THE EFFECTS OF EXERCISE ON THE LACTATIONAL PERFORMANCE OF CATTLE

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PhD

UNIVERSITY OF EDINBURGH

1989

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ABSTRACT

The aim of this work was to investigate the effect of exercise (walking a specified distance for a fixed number of days) on the lactational performance of pregnant cows and to investigate the effect of diet on the lactational response to exercise. The results of the reseach are particularly applicable to the effects of exercise on the lactational performance of cows which are used as draught animals in tropical countries.

A literature review was carried out of the role of cows as draught animals in tropical farming systems, of the metabolites used for muscular activity and lactation, factors which affect the supply of these metabolites and the effect of exercise on lactational performance, body weight change and food intake.

Three experiments were done to investigate the effect of exercise on milk yield, milk constituent yield (g/d), milk constituent content (g/kg milk), body weight change, blood metabolite concentrations and the voluntary intake of barley straw. The effect of five different diets on the response of the above variables to exercise was also investigated.

The experiments were carried out at the Easter Howgate Farm six miles south west of Edinburgh using in each instance twelve pregnant, lactating crossbred Hereford x Friesian cows in their second or subsequent lactations. The animals were exercised in the

Pentland Hills for three five day periods each separated by two non-walking days. They walked approximately 8.8 kilometres each day and climbed a vertical distance of approximately 480 metres a day. This exercise was calculated to be equivalent to an energy expenditure of approximately 12MJ per day or a quarter of the maintenance energy requirement of the animals.

It was found that the exercise carried out caused a milk yield reduction of between 7 and 14 percent depending on diet. Milk yields declined on walking days and recovered to almost non-walking levels on the intervening non-walking days. Milk fat content increased as milk yield declined, with the result that the daily yield of milk fat was not affected by exercise. Milk protein content and lactose content were not markedly affected by exercise, with the result that the daily yields of these two milk constituents declined approximately in proportion to the decline in milk yield.

When animals walked, their rate of weight gain was not as great as when they were not walking. Animals on some diets lost body weight when they walked. After walking animals on all diets increased weight faster than prior to the walking period and in most cases achieved the expected weights (based on extrapolations from the first non-walking period weight gains) by the end of the experiment. It appeared that exercise may have caused changes in gut-fill which influenced body weight.

Measurements of the concentrations of blood metabolites showed increases in the concentrations of β-OH butyrate and free fatty acids and decreases in the concentrations of glucose, magnesium and

inorganic phosphorus. The response of blood metabolites to exercise was influenced by diet and some adaptation to exercise was observed over the three week walking period. These changes were indicative of energy deficits when the animals exercised and in some cases were similar to the changes in blood metabolites observed by other authors in fasting animals.

The intake of barley straw offered *ad libitum* and supplemented with one of three diets was not affected by exercise.

No measurements were made of the products of digestion, but it appeared that diets which might be expected to sustain high rates of fermentation and high levels of propionate production supported lactational performance during exercise better than diets which were designed to supply larger quantities of rumen undegradable protein and starch.

It was calculated that cows offered some diets were in energy deficit when they walked and concurrent weight losses were observed. In other groups however, although cows were in negative energy balance, positive weight gains were measured. Gut-fill changes, increased weight of concepta and changes in fat to lean tisue ratio might explain these observations.

No adverse effects of exercise were observed in the animals and all animals subsequently calved successfully.

It was concluded that the levels of energy expenditure experienced by the cows in the present experiments would have no long-term adverse effects on the lactational performance of the animals and that while milk yields would suffer in the short term, if working periods were separated by two or more non-working days,

milk yields would recover to near pre-work levels. The consequences of heavier work, greater daily levels of energy expenditure, work sustained for longer periods of time without intervening non-working days, work carried out at different stages of lactation and work carried out by animals fed tropical diets is worthy of further investigation.

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ACKNOWLEDGEMENTS

Over the period of this research I have accumulated many debts of gratitude to my colleagues, friends and others who have helped in various ways. I would like to offer my thanks to all staff of the Centre for Tropical Veterinary Medicine for the support given me throughout this work and for the atmosphere of friendship and professionalism fostered by them in the Centre.

I would particularly like to thank **Professor David Brocklesby** for permitting me to carry out this research in addition to my normal workload and **Tony Smith** who has been a constant companion over the six year period for his unfailing support.

Anne Pearson has provided sustained encouragement and has always been ready to give time for advice and discussion. Similarly, **Denis Fielding** has patiently provided time within my teaching responsibilities to carry out my research work. I am greatly indebted to them both.

The scientific exactitude and expertise which has characterised **John Oldham's** supervision and advice has been invaluable. It has been an inspiration to work with **John** and if a little of his sparkle has rubbed-off, my future research should fare well.

The experiments could not have been carried-out without the help of **Jane Merrit, Bob Archibald, Iain Campbell, Peter McCluskey** and **Paul Hamilton** from CTVM. They helped with milking, exercising the cows and assisting with the other routine aspects.

Milk analysis was carried-out by **Zoe Gray** and **Rhona Muirhead** of the Veterinary Field Station and **Harry Ferns** and his staff at the West of Scotland College of Agriculture. I am grateful for the advice on blood analysis given me by **David Whitaker** and **Jim Kelly** of the Dalgety Herd Health and Productivity Scheme and for the analyses carried out by **Gill Smith, Zoe Gray** and **Alex Dowell.**

I am grateful for the guidance afforded me by **Helen Talbot, Helen Sutherland** and **David Nielson** at the Edinburgh Computing Centre and to **Pat Phillips** from the Scottish Agricultural Statistics Service for advice on carrying out the statistical analyses. In addition I am grateful to **Gerry Emmans, Mitch Lewis, Colin Morgan, Basil Lowman** and **Peter Lawrence** for discussion throughout the research programme.

Also deserving thanks are the Farms Division Staff of ESCA: the Director, **Murray Black,** Farm Managers **Ashley Thom** and **Lawrence Hodgson-Jones** and **Cathy Peebles, Dougy Watt** and **John Murchie** at the Beef Unit. I am also grateful to **Neil Scott** for condition scoring the animals.

Exercising the cows was probably the hardest task each day and threatened to break the camel's back on many occassions. Numerous

people not mentioned above also helped to move the cows along. These included **Anne Pearson, Patrick Janga, Narayan Shrestha** and **Robert Muyunda** as well as all members of my family, **Judyn, Matthew, William, Thomas** and **Naomi** - without whom the experiments could not have been completed. They also helped with routine milking when other staff were not available, mainly at weekends and in the evenings.

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DECLARATION

I, RICHARD WARWICK MATTHEWMAN, hereby declare that this thesis was composed by me and that the work described was my own.

6.11.89.

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CHAPTER ONE

INTRODUCTION

Draught animals provide the tractive effort for cultivation and transport in many countries and are a major element of agriculture on a world scale, particularly in the tropics. Oxen are often the preferred draught animal, but cows are used where land and feed resources for ruminants are scarce. Where pressure on land is high, large male draught animals tend to be excluded in favour of smaller female animals. The situation in Bangladesh is a good example of this inter-relationship. The use of cows in Hindu countries such as India is discouraged because of the religious role of cows, though even in India some cows are used for draught power production.

While the use of cows for draught power production may have advantages in farming systems where there is pressure on land, their use for work poses management problems and also nutritional problems related to the ability of the diet to meet the competing requirements of lactation, pregnancy and work. The nutrient demand of work may cause a reduction in the supply of nutrients, particularly glucose and glucose precursors, for lactation and growth of concepta.

Nutrient requirements and partition for maintenance, growth, lactation and growth of concepta have received much attention and have been relatively well researched and documented, but

requirements for work and the partition of nutrients in working animals are less well understood. The provision of balanced rations for tropical female draught animals, which often survive on poorer, roughage-based diets, also has received little attention. The effect of the extra energy demands for work on lactational performance may vary depending on the plane of nutrition, the condition of the animals and whether the animal is pregnant or not.

Uncertainty and lack of understanding about the interactions between work and lactation and the impact which work may have on milk yield and other production functions stimulated the present investigation. As well as its intrinsic value, a greater understanding of these interactions may provide information on which to base management and husbandry advice to farmers using cows for draught power production in tropical countries.

As a preliminary part of the investigation, a review of the literature was carried out to determine the importance of cows as draught animals in tropical farming systems. This was followed by a more general review of metabolite supply and partition of metabolites for lactation and exercise in ruminants, and of the factors which affect this such as food intake and diet composition. Previous research which has investigated interactions between work and lactation is described. The literature review is presented in Chapter Two. A summary of the review and the objectives of the research programme are presented in Chapter Three.

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LITERATURE REVIEW
AND OBJECTIVES OF THE RESEARCH PROGRAMME

CHAPTER TWO

LITERATURE REVIEW

In the following chapter the role of draught animals in tropical farming systems is outlined and the relative value of female animals for draught power production compared with draught oxen is considered. Subsequently aspects of draught cow nutrition including the metabolites produced by digestion, the metabolites produced endogenously in the tissues, the metabolites available for muscle function and lactation and factors which affect the supply of metabolites are considered. These include food intake, diet composition, dietary protein supply and environmental factors. Finally the ways in which exercise affects food intake, digestion, body weight change and lactational performance are discussed.

2.1. DRAUGHT ANIMALS IN TROPICAL FARMING SYSTEMS

Draught animals are used throughout the world, and in many areas are as important now as in the past. In Ethiopia for example, the most important contribution of livestock in highland areas is reported to be for draught power production (Gryseels and Anderson, 1983). In other parts of Africa such as Senegal (Munzinger, 1982) and Zambia (Milimo, 1985) draught animal use is reported to be increasing. In Egypt buffaloes provide 30 to 40 percent of farm power, and although mechanisation has been widely adopted, the buffalo is again attracting attention (Shalash, 1983). Draught animals in South

East Asia are the most important consumers of food and labour resources amongst the livestock populations, and play vital economic and social roles (Petheram, Thahar and Bernsten, 1985).

In Bangladesh the demand for draught animals in 1978 was 11.5 million (one pair for every 1.7 hectares), but Ahmed (1978) considered that this demand was unlikely to be met, even if cows were used. In China, Indonesia, Korea and the Philippines, 98 percent of farm power is derived from animals and in Thailand 95 percent of rice production depends on draught animal power (Chantalakhana, 1981). Singhal and Tomar (1982) quoted a figure of 44 percent of cultivation being carried out by draught animals in India.

Unlike Asia, Africa until recently has had a relatively low human population density and cultivation was based on slash-and-burn systems, with long fallows to maintain fertility. This did not encourage animal-drawn implements for cultivation. In many parts of Africa the presence of tsetse and trypanosomiasis also excluded cattle. Under these circumstances hand-tillage predominated. Human population pressure on land has now increased, fallow periods have reduced and land is often under almost permanent cultivation. Trypanosomiasis has been controlled in many areas and the cost of mechanical farming has risen. As a result of these changes draught animal use has increased in some areas.

These examples indicate the importance of animal power in the tropics, where the demand has increased and often cannot be met by oxen alone. Cows are used at peak periods and where

cultivation pressure has caused a decline in ruminant populations, cows are now more commonly used for draught. Since these changes are likely to become more widespread, it is also likely that cows will be used more widely.

2.2. THE IMPORTANCE OF FEMALE ANIMALS FOR DRAUGHT

Various authors (Suntraporn, 1975; Chantalakhana, 1981; Gill, 1981; Mettrick and James, 1981; Munzinger, 1982 and Kibria, 1982) comment that in many countries oxen have been preferred for work because of their larger size. Despite this, in certain countries, cows are now commonly used.

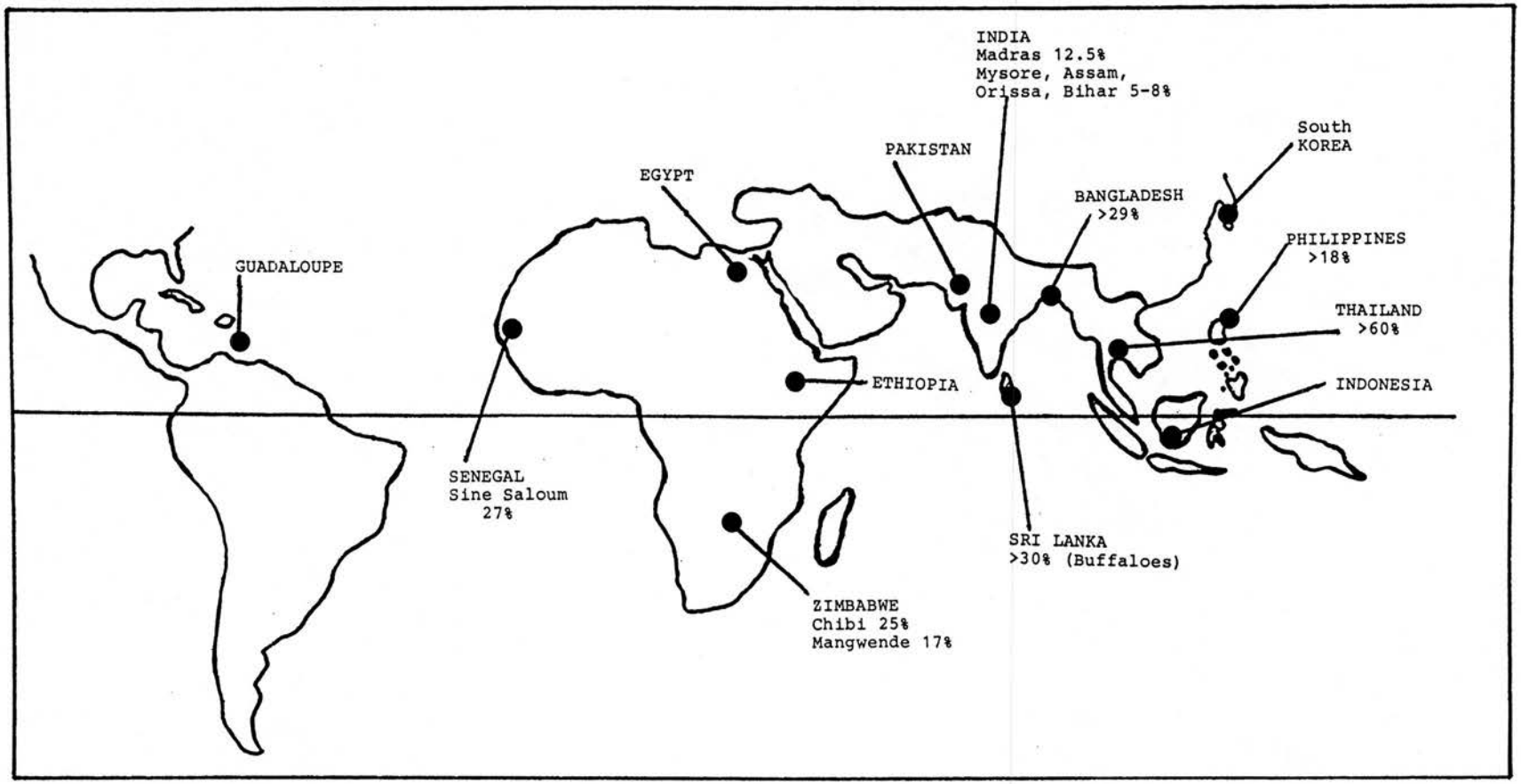
In much of Asia and the Pacific region, a constraint to production and draught animal use is the small size of holdings. The human to land ratio of this region is the lowest in the world and has been decreasing. It was 0.28 ha/person in 1963 and has come down to 0.21 ha in 1980 (Puri, 1982). In Egypt, land availability is also one of the major constraints to increased agricultural production. Under conditions of small farm size, female draught animals have an important role to play. In Bangladesh cows are stated to be more efficient (in terms of energy input and output) than bullocks, since the cost of maintenance for a cow can be offset against relatively greater production (milk, calf, meat and work) (Dolberg, 1981). In parts of Africa also, high human population densities are placing pressure on land and food resources for livestock (eg. in the Kenyan Highlands and parts of Nigeria). In these areas female draught animals may have an increasingly important role to play.

Bartlett and Gibbon (1984), stated that while few studies exist, the general opinion is that with careful management much could be gained from using cows rather than bullocks for draught power production.

Female animals are used for agricultural work in many countries and some of these countries are shown in Figure 2.1.

In India it was acknowledged as early as 1949 that a solution to the dwindling draught oxen population would be the use of cows (Anon, 1949). In Bangladesh cows are used on small farms where feed resources are likely to be scarce, and bullocks are used on larger farms (Orr, Islam and Haq, 1986; Barton, 1987a, b). In Sri Lanka in one district surveyed, 75% of farmers used lactating cows for work with an average of 36% of farmers for all five districts surveyed (Kumaratileke and Buvanendran, 1979). An average of 23% of farmers in all districts used pregnant cows for draught. In Pakistan 85% of farmers have depended in the past on animals for cultivation (Akhtar, 1981), though recent increased use of tractors may have affected this dependency on draught animals. Bullocks and buffalo bulls are used for draught, but cows and female buffaloes are also important, particularly in the drier areas. In South Korea although bulls are preferred for ploughing, in practice about 75% of draught animals are cows (Anon, 1978). In the Philippines caracows (female swamp buffaloes) are noted for their draught qualities (Ranjhan, 1983). Rollinson and Nell (1973) reported that cows are used in parts of Indonesia. Java for example, is an area of high human and stock density, high cropping intensity

Figure 2.1. The use of cows for draught power production in some tropical countries



Sources: Rajapurohit and Muranjan, 1965; Anon, 1978; Harbers, 1981; Guzman and Perez, 1981; Kibria, 1982; Sharma, 1982; Lhoste, 1983; Slangantillake, 1983.

and rapid urbanisation (Petheram, Thahar and Bernsten, 1985). Mainly adult females are kept and in some villages mature buffalo bulls are very scarce. Draught cows in Java are not milked, but reduced milk yields due to work may affect calf growth.

In Poland, Red and White Cows weighing between 500 and 650 kg are used for work (Sasimowski, Slomka and Halewicz, 1984). Average time spent working is 4 to 8 hours per day for transport, harrowing, sowing, ploughing and other work. Mean yearly milk yield was reported to be 3464 litres with a maximum daily yield of 17 litres.

Cows are used in some countries in Africa. In Senegal eleven year old cows can apparently work with no adverse effect for 350 hours per annum (Nourrissat, 1965). In Egypt the principal sources of power in agriculture are cattle and buffaloes (Morgan-Rees, Williams, Smith and Capper, 1977). Adult male buffaloes are not considered suitable for draught purposes and the main source is adult female cattle. Cows in milk are worked and dry animals are worked up to two months before calving (Shalash, 1983). In Ethiopia where oxen are preferred for draught, an intensive dairy system in which cows would be used for both traction and milk production using Friesian x Boran cattle has been proposed for research (Gryseels and Anderson, 1983). Tests at Uyole Agricultural Centre in Tanzania have shown that the same work output per day can be derived from cows as from oxen. They were less strong and lighter, but they pulled more consistently and at higher speeds. Oxen are the main

draught animals in Zambia, but it is recognised that cows may have a role to play (Rep Zam, 1985). Cows are also used for power production in Zimbabwe (Zimbabwe, 1985).

2.3. EFFICIENCY, ADVANTAGES AND DISADVANTAGES OF COWS

Because oxen are usually heavier than cows they provide a greater work output (FAO, 1972). Evidence suggests however, that where cows are used, they can usually achieve the necessary work output for cultivation and transport on small farms. N'dama cattle in Sierra Leone are small, but are used successfully for draught. Timing the work requirement so that energy demands are spread-out and work does not overlap with parturition is important, but puts additional management demands on farmers.

When considering the suitability of animals for draught power production, overall productivity must be considered. Smith (1980) pointed out that draught animals compete for food with animals that are used for meat and milk production. If an animal can be used to produce all these, then the costs of supporting the animal could be spread over all the products. Using a greater number of female animals for draught has advantages in terms of village herd structures by increasing the proportion of cows.

The disadvantages of cows include lower body weights and tractive power, the possible effects of work on milk yield and reproductive rates, and the possibility that cows may be unavailable for work for two to four months per annum around calving (Mettrick and James, 1981; Munzinger, 1982). There are

however, a considerable number of tasks that do not require large tractive effort.

Lhoste (1983) states that newly settled agropastoralists in Senegal recognise many advantages to the use of cows. These include the facts that cows are said to be easier to train than oxen, they can be used over a longer period than oxen thereby reducing the need to train animals frequently, a farmer can breed his own replacements and cows are more efficient than oxen.

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2.4. SOURCES OF METABOLITES FOR MUSCLE METABOLISM AND LACTATION

Numerous energy metabolites are available for the working ruminant, some of which are produced exogenously from the products of digestion and others which are synthesised endogenously in the tissues or from stores and the breakdown of tissues. The diets of tropical draught animals are usually based on fresh roughage, crop residues and by-products. Concentrate foods are unlikely to be used to any great extent in most cases. The main energy yielding metabolites derived from ruminant diets are **acetate, ketone bodies (β-OH butyrate** and **acetoacetate), glucose** and **glucose precursors** (mainly **propionate, lactate, pyruvate, glycerol,** and **amino acids), free fatty acids** (and other lipid derivatives such as **triglycerides**) and **amino acids.**

Depending on the diet, greater or lesser quantities and proportions of these metabolites will be produced to sustain productive functions in working animals.

2.4.1. SOURCES OF ACETATE

Acetate is produced exogenously in the rumen and lower gut (Mann and Orskov, 1973) and is synthesised endogenously in the tissues (Annison and Armstrong, 1970). It is produced and used by all tissues, but exogenous supply is the most important determinant of circulating levels in sheep (Pethick, Lindsay, Barker and Northrop, 1981). Acetate is readily absorbed into the blood stream and high blood concentrations occur in fed animals. 0.25 of total turnover may be from endogenous sources in fed sheep and 0.50 to 0.75 in fasted sheep.

Acetate is quantitatively the most important of the rumen volatile fatty acids (VFA) (acetic, propionic and butyric) which are usually found in the ratio 65:20:10, depending on diet, with other minor VFAs, (mainly iso-butyric, iso-valeric and n-valeric) making-up the remainder. These ratios are similar to those produced in the caecum in sheep (Mann and Orskov, 1973). Acetate levels are highest on roughage diets, the proportion decreasing as the level of dietary concentrate increases. Other dietary factors which affect the ratio include the level of feed intake, the type of forage and concentrate, levels of succulents and soluble carbohydrates and the pattern of feeding (Sutton, 1980). VFAs are the main products of rumen fermentation and account for 0.60 to 0.80 of ME intake (Annison and Armstrong,

1970). A similar figure of 0.70 energy requirement being met by VFAs was given by Bergman (1973).

Endogenous synthesis occurs mainly in the liver and in the lactating mammary gland by the oxidation of free fatty acids. Synthesis in the liver is reported to account for 0.77 of endogenous production in fasted sheep (Pethick, Lindsay, Barker and Northrop, 1981). Levels of endogenous production from free fatty acids differ in fed and fasted animals. In fed animals less than 0.02 of plasma acetate was found to be derived from palmitate for example, but this increased to 0.16 in fasted animals (Palmquist, 1972).

2.4.2. SOURCES OF KETONE BODIES

The primary ketones are β-OH butyrate and acetocetate. Blood ratios in ruminants are about 10:1, in contrast to non-ruminants where acetoacetate predominates. Concentrations of ketone bodies are high in fed ruminants and both are readily used by extrahepatic tissues after conversion to acetyl CoA. β-OH butyrate is produced in the rumen epithelium from butyrate which accounts for 0.80 of ketogenesis, with minor contributions from acetate or free fatty acids (Leng and West, 1969). This is a special feature of ruminant metabolism (Annison, 1984). In fed lactating cows, the ketogenic activity of the liver also may be significant (Snoswell, Costa, McLean, Baird, Lomax and Symonds, 1978). The main liver precursor in fed animals is probably butyrate which has escaped metabolism in the rumen epithelium.

In fasted animals also, β-OH butyrate is a quantitatively

important energy source. In fasted ewes for example, ketones oxidised to CO_2 accounted for 0.30 of CO_2 production (Pethick and Lindsay, 1982a). The contribution of free fatty acids to β-OH butyrate production rises in fasted animals with a fall in synthesis from rumen butyrate.

2.4.3. SOURCES OF GLUCOSE

In the ruminant, as a result of microbial fermentation, little glucose is absorbed from the gut and only small amounts of glucose can usually be detected in the rumen fluid. Dietary carbohydrates are converted in the rumen to pyruvate, which is converted by rumen microbes to volatile fatty acids. Ruminants therefore rely largely on tissue glucogenesis to meet glucose needs. Under certain circumstances small amounts of carbohydrate may escape rumen fermentation and these contribute to blood glucose via digestion in the small intestine.

Glucogenesis occurs mainly in the liver (and kidneys) from **propionate, lactate, pyruvate, glycerol** and **amino acids** (Leng, 1970; Bergman, 1973; Young, 1977). The rate of glucogenesis is greatest after feeding and normally 0.90 to 1.00 of circulating glucose is derived from glucogenesis (Armstrong, 1965). The liver produces 0.80 to 0.90 of glucose and the kidneys the remainder. In fed ruminants the principal precursors are propionate and amino acids. During starvation glycerol replaces part of the propionate, but most glucose is apparently formed from amino acids. Alanine and glutamine seem to be the principal amino acids involved (Bergman, 1973).

Endogenous glucose precursors such as lactate, pyruvate and glycerol can be converted to glucose in the liver and kidneys. In sheep renal synthesis accounts for approximately 0.10 of glucose synthesised, of which about 0.65 originates from lactate and pyruvate and 0.12 from glycerol (Kaufman and Bergman, 1974). These sources of glucose are discussed in the next sections.

2.4.3.1. PROPIONATE

Propionate produced in the rumen is usually quantitatively the most important glucogenic precurser, but its assessment is complicated because some propionate is metabolised to lactate during its passage across the rumen epithelium (Bergman and Wolff, 1971). Most of the propionate absorbed from the rumen is removed by the liver where it is used for glucogenesis (Baird, Symonds and Ash, 1975).

Using constant infusion isotope techniques, Wiltrout and Satter (1972) found that 0.40 to 0.60 of glucose synthesised in fed lactating and non-lactating cows originated from propionate carbon. These authors found that propionate contributed a minimum of 0.45 of blood glucose entry rates in lactating cows and 0.32 in non-lactating cows. These were minimum values based on transfer of Pr-2-^{14}C to glucose. Estimations based on this type of tracer study can be complicated by the 'changeover' of ^{14}C label from propionate to lactate and other intermediates such as pyruvate. Similarly, 0.20 to 0.57 of glucose synthesised in fed sheep may originate from propionate carbon (Bergman, Roe and Kon, 1966; Leng, Steel and Luick, 1967). On half maintenance

diets, Bergman *et al* (1966) found that 0.20 of glucose was derived from propionate. In fasted sheep, no propionate is absorbed and the animal's pattern of glucogenesis must change to a dependence on other endogenous precursers such as glycerol, fatty acids and amino acids.

2.4.3.2. LACTATE

Lactate is not usually detectable in the rumen of animals fed on high roughage diets, except when silage is fed, but is an intermediate in the fermentation of starch and soluble sugars and is found in measurable amounts when high carbohydrate diets are fed (Annison, 1965). In adapted animals, micro-organisms convert lactate to propionate. High levels (139.3g/kgDM) of lactic acid in silage were reported by Gill, Siddons, Beever and Rowe (1986). Lactate was largely metabolised in the rumen (0.55 to acetate and 0.31 to propionate). Lactate appeared to make no direct contribution to glucose flux, but 0.10 of the total lactate was converted to glucose through propionate.

Blood lactate is partly derived from the conversion of propionate in the rumen epithelium, but at most 0.15 of propionate is metabolised to lactate in the rumen epithelium (Baird, Symmonds and Ash, 1975).

Under normal condition a cycling of carbon between lactate and glucose occurs. Approximately 0.15 of blood glucose was calculated to be derived from lactate carbon in fed sheep (Annison, Lindsay and White, 1963) and at least 0.40 of the lactate pool was in turn derived from glucose. This production

apparently however, does not involve recycling from muscle glycogen to lactate, liver glycogen, glucose and back to muscle glycogen (ie the 'Cori Cycle'), as described in rats by Cori and Cori (1928a, b, c), which may only occur under the action of adrenalin or exercise.

Lactate was the predominant metabolite removed by the kidneys of pregnant and non-pregnant sheep fed *ad libitum* legume hay (Kaufman and Bergman, 1974). Lactate can account for 0.40 to 0.60 of net renal glucose output, which in turn accounts for approximately 0.10 of glucose synthesised. The kidneys also take-up pyruvate and glycerol (see sections 2.4.3.3 and 2.4.3.4) and these can account for 0.20 to 0.30 of renal glucose output. These three substrates therefore account for 0.70 to 0.80 of renal glucose output and the rest is made up from amino acids (Kaufman and Bergman, 1974).

2.4.3.3. PYRUVATE

In glycolysis in actively working animals, pyruvate is reduced mainly to lactate. This diffuses to the blood and is passed to the liver, kidneys and heart for further metabolism. In the liver and kidneys it may be reconverted to glucose and then back to glycogen in muscles. Such recycling of glucose carbon is of more significance when normal glucogenic substances are at low levels, as in underfeeding or when demand for glucogenesis increases in pregnancy, lactation and work (Leng, 1970).

2.4.3.4. GLYCEROL

Ruminant blood glycerol levels are normally low, but during periods of fat mobilisation (ie during starvation, ketosis, undernutrition or during early lactation and probably when animals are working) glycerol is released from adipose tissue along with free fatty acids. It enters the glycolytic pathway and glucose is produced by a reverse of glycolysis via fructose 6 phosphate and glucose 6 phosphate.

Glycerol is utilised mainly by the liver (0.80 to 0.90) and the kidneys and converted to glucose (Leng, 1970). In starved sheep, glycerol carbon was found to contribute to 0.23 of blood glucose, compared to 0.05 in fed sheep (Bergman, Starr and Reulein, 1968). Leng (1970) concluded that glycerol contributes little to glucose synthesis in fed sheep, but that in starved sheep, endogenous glycerol is important for glucogenesis. At the highest rates of glycerol turnover in the experiments of Bergmann *et al* (1968), about 0.35 to 0.40 of glucose originated from glycerol. These authors considered that glycerol could replace a maximum of 0.50 of propionate glucose production.

2.4.3.5. AMINO ACIDS

Many amino acids, particularly alanine and glutamine (Bergman, 1973) are glucogenic and are thought to play an important role in glucose synthesis, particularly when glucose is limiting. Earlier work suggested that 0.30 to 0.50 of glucose entry rate may arise from amino acid carbon (Black, Egan, Anand

and Chapman, 1968) and in sheep that 0.11 to 0.30 of glucose turnover may be derived from amino acids (Trenkle, 1980).

The glucogenic role of specific amino acids is demonstrated by the work of Egan and Black (1968). Glutamic acid is a major component (0.20) of milk protein, but only 0.04 to 0.06 of glutamate C-14 was recovered from milk proteins after 48 hours, whereas recovery from lactose was higher. Similarly, Hunter and Millson (1964) showed that 0.12 of milk lactose was synthesised from glucose derived from amino acids in lactating cows.

The competing demands for amino acids for protein synthesis and glucogenesis were further considered by Girdler, Thomas and Chamberlain (1986) whose work indicated a clear substitution of amino acids for propionate or glucose which they supplied intra-ruminally or intra-abomasally by infusion. Nitrogen retention increased with propionate and glucose supply. This again indicated competition for amino acids between protein synthesis and glucogenesis.

The high levels of glucose synthesis from amino acids reported by some authors contrast with those found by Oldham (1978) who, in agreement with Lindsay (1970), suggested a lower level (0.05) for cows in early lactation when amino acid supply may be small relative to demand. Lindsay (1970) discussed several objections to earlier work, which he considers may have led to overestimations of the amount of glucose derived from amino acids. Oldham and Smith (1982) state that in lactating cattle the net contribution of amino acids to glucogenesis is small relative to total glucose demands. From these

contradicting reports, it would appear that the contribution of amino acids to glucogenesis is not totally clear.

2.4.3.6. VALERIC AND ISOBUTYRIC ACIDS

Although these acids are glucogenic, they contribute only small amounts of glucose (Leng, 1970; Lindsay, 1978).

2.4.3.7. DIETARY CARBOHYDRATES

Digestible carbohydrates which escape rumen fermentation may be digested in the small intestine. This will be referred to in greater detail in section 2.6.2.

2.4.4. SOURCES OF ESSENTIAL AND NON-ESSENTIAL AMINO ACIDS

In fed ruminants the portal blood contains amino acids produced from the digestion of microbial and dietary protein as well as those of endogenous origin. On diets containing mainly fermentable nitrogen sources, most dietary nitrogen is converted to microbial protein which is digested in the small intestine (ARC, 1980, 1984). On diets which contain larger amounts of undegradable protein, a greater proportion of the dietary protein escapes rumen fermentation and passes directly to the small intestine for digestion.

A proportion of the absorbed amino acids is removed and metabolised by the liver and the remainder transported to the tissues for synthesis or replacement of body protein, milk synthesis, glucogenesis or oxidation. Alanine is usually the most abundant amino acid in portal blood (Hume, Jacobson and

Mitchell, 1972). In fasting animals there is a net endogenous output of amino acids from muscle.

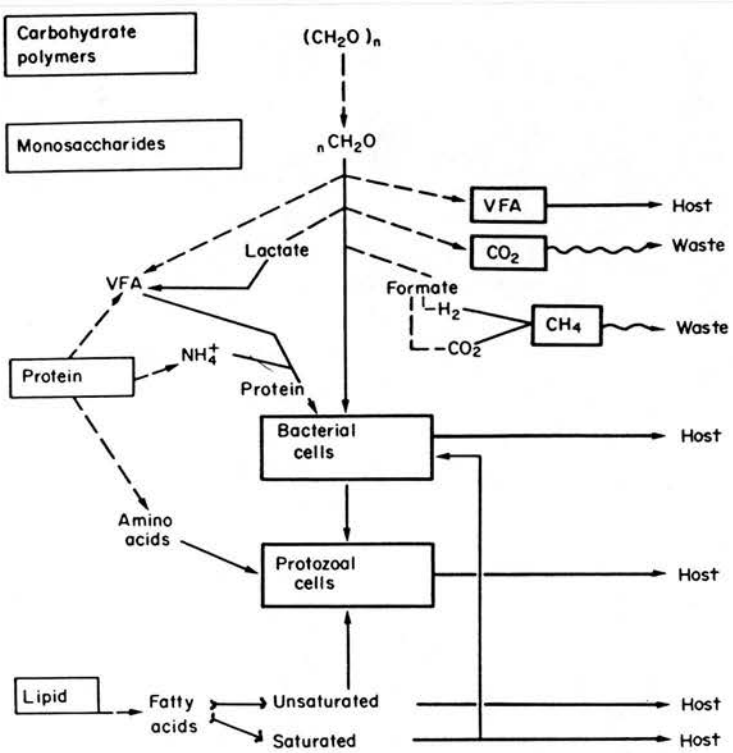
2.4.5. SOURCES OF FREE FATTY ACIDS

The four main metabolically active lipid derivatives are acetate, β-OH butyrate, glycerol and free fatty acids (LCFAs/NEFAs) (Annison, 1984). Palmitic, stearic and oleic acids account for most of the fatty acids in adipose tissue and of free fatty acids (Vernon, 1981).

In forage feeds lipids are found mainly in leaves and constitute 0.06 to 0.08 of leaf tissue of which 0.80 are glycolipids and 0.20 phospholipids (Harfoot, 1981). A 500kg cow consuming 15kg DM would ingest 750 to 1500g lipids daily. On forage diets, triglycerides constitute only a small fraction of the lipids ingested, but the importance of dietary triglycerides increases on concentrate diets. Rumen microbes also synthesise lipid (Sutton, 1985).

The relationship between lipid digestion in the rumen and other processes was described by Harfoot (1981) and is shown in Figure 2.2. Dietary glycerides are rapidly hydrolysed in the rumen to free fatty acids (mainly unsaturated of which the principal acids are oleic, linoleic and linolenic. 0.80 to 0.90 of these are hydrogenated to stearic acid (Bickerstaffe, Noakes and Annison, 1972) which passes from the rumen adsorbed on digesta. Dietary and rumen synthesised fatty acids are absorbed predominantly in the free form and are esterified to triglycerides (in the form of chylomica), phospholipids and

Figure 2.2. Integration of major metabolic activities occurring in the reticulo-rumen (Harfoot, 1981)



----, degradation; ⟶, synthesis; ⟶ Host, used by host animal; ⇝ Waste, waste product.

cholesterol esters in the intestinal mucosa (Tove, 1965).

In the blood, lipids are also found in association with protein as lipoproteins. Phospholipids are important in cell membrane structure and function, but are quantitatively less important than other derivatives.

Adipose tissue triglyceride can be mobilised as free fatty acids which are transported to tissues bound to plasma albumin. Plasma free fatty acids release, as indicated by circulating levels, is closely related to nutritional status. The low levels (0.2 to 0.3 mmol/l) characteristic of fed animals rise sharply in starvation (Vernon, 1981).

The supply of metabolites in fed and fasting ruminants is summaried in Figure 2.3.

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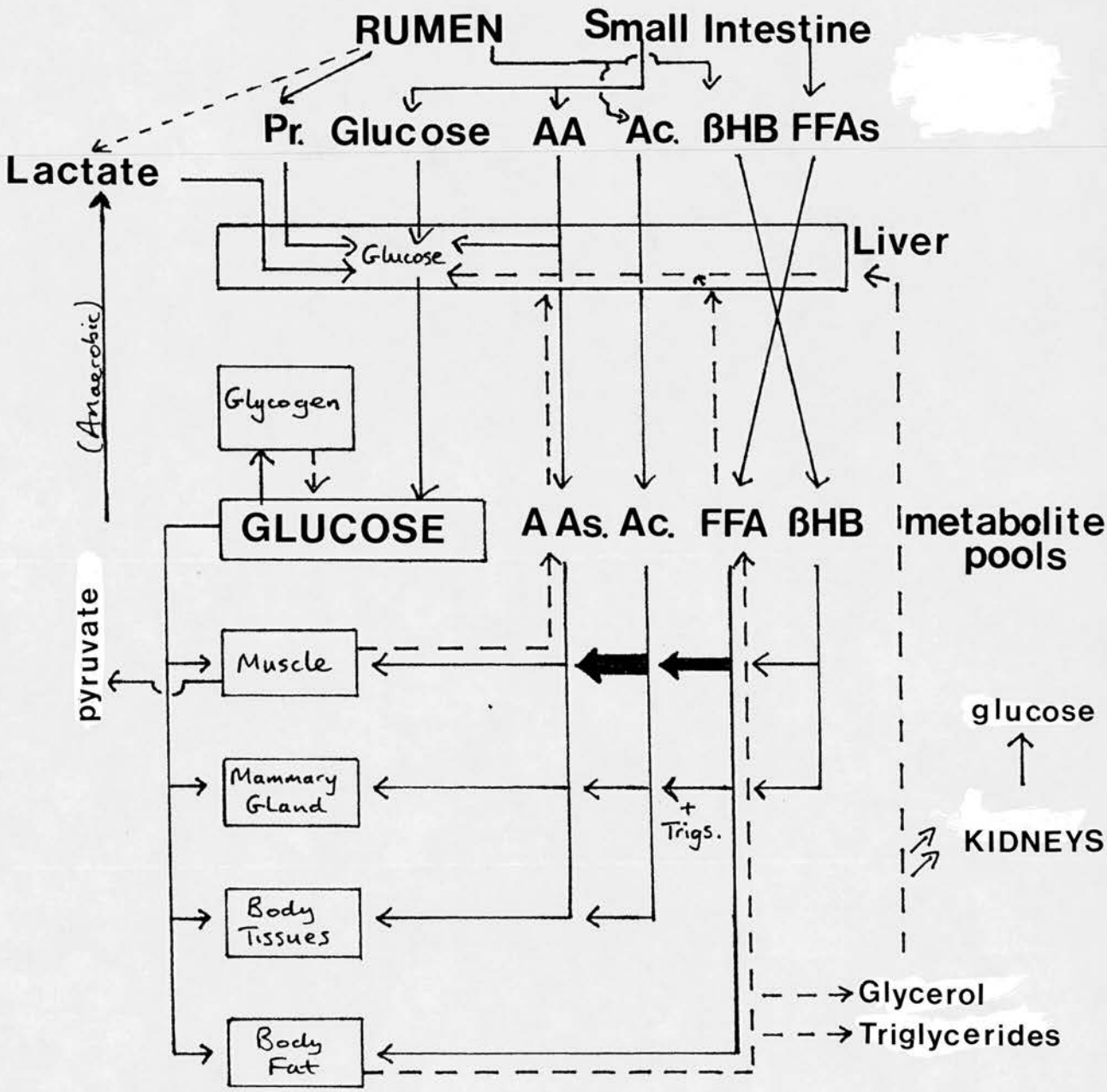
Figure 2.3. Summary of metabolite supply to muscle, the mammary gland, body tissues and body fat in fed and fasting ruminants



2.5. METABOLITES USED FOR MUSCULAR WORK AND LACTATION

2.5.1. SUBSTRATES FOR MUSCULAR WORK

The circulating substrates available for muscle metabolism are **acetate, ketone bodies, free fatty acids and glucose** (Jarrett, Filsell and Ballard, 1976; Leng, 1985). Additional sources of potential energy for muscular work include **glycerol** and the **glycogen** present in body tissues. Resting muscle has reserves of triglyceride and glycogen which can be oxidised directly to supply ATP for contraction. **Amino acids** also represent a potential, but minor source of energy. **Lactate** can also be used as an energy source.

In fed ruminants, acetate rather than free fatty acids is the most important energy source and its oxidation is considered to account for up to 0.50 of the total CO_2 produced in the tissues of the lactating dairy cow (Bickerstaffe, Annison and Linzell, 1974). For resting skeletal muscle, acetate and glucose appear to be significant substrates, with lesser roles for free fatty acids. In working muscle the utilisation of acetate, glucose and free fatty acids increases, with the greatest increase being for free fatty acid (Bird, Chandler and Bell, 1981 (Table 2.1).

In sheep, Pethick *et al* (1981) found that muscle accounted for 0.54 of acetate entry rate (compared with 0.17 and 0.25 for liver and gut respectively). Acetate was largely oxidised to CO_2 in the gut and muscle and may account for 0.30 - 0.40 of the oxidative metabolism of these tissues.

Jarrett *et al*, (1976) attached a greater importance to free

Table 2.1. The uptake of metabolites by the resting and exercising hind-limb of the sheep (Bird, Chandler and Bell, 1981)

	Hind Limb Uptake ($mmolmin^{-1}$)			
	Acetate	Glucose	Lactate	FFA
Resting Muscle				
Maintenance	73±16	19±4	5±8	2±1
1.5 Maintenance	71±15	16±3	5±7	2±3
Exercising Muscle				
Maintenance	82±14	71±20	1±34	70±29
1.5 Maintenance	143±16	38±12	5±9	59±15
Exercise	*	*	ns	*
Nutrition	ns	ns	ns	ns

fatty acids as a primary energy source and state that free fatty acids rather than acetate are the major nutrient utilised by the hind limb of fed sheep and become especially significant during exercise. These authors postulated that acetate may be first converted to acetoacetate, β-OH butyrate, free fatty acids or triglyceride rather than being directly oxidised in the muscle. These nutrients could then serve as acetate stores for periods of fasting or exercise when absorption of acetate from the rumen may be restricted. This view however, is challenged by Pethick, Harman and Chong (1987), who consider that the view should be reappraised. They found that in fed, non-pregnant, non-exercising

sheep all parameters of free fatty acid metabolism (plasma concentration, entry rate, contribution to whole animal oxidation and utilisation by skeletal muscle) indicated a minimal role for oxidation. Exercise prompted a shift to lipolysis and the above parameters increased markedly. Glucose utilisation by skeletal muscle also increased.

In starved sheep glucose and acetate make a negligible contribution to energy supplies, while the role of glycerol, free fatty acids, acetoacetate and β-OH butyrate increase (Jarrett *et al*, 1976). Free fatty acid oxidation accounted for most (0.57) of the oxygen uptake and glucose accounted for 0.27.

In exercising fed sheep, increased blood concentrations of glucose, lactic acid and free fatty acids have been shown to occur and uptake of glucose and free fatty acids to increase (Bird *et al*, 1981). In exercising pregnant ewes (Chandler and Bell, 1981) and exercising fed wethers (Jarrett *et al*, 1976) blood glucose concentrations have been shown to increase. In exercising sheep acetate and ketones play a smaller proportional role as energy substates. The lower use of acetate during exercise is probably due to its low rate of extraction which limits its usefulness as a nutrient compared with free fatty acids which are readily available from triglyceride stores and can be rapidly oxidised. The earlier reported work supported Pethick's work, in which increases in the utilisation of free fatty acids and glucose were demonstrated after 120 minutes of working in the hind limb of the fed sheep (Table 2.2) (Pethick, 1984).

Leng (1985) suggests that glucose availability may be an

important constraint to work, particularly if growing animals or productive females are used. This may be true despite the animal's ability to synthesise glucose at differential rates according to productive function (Preston and Leng, 1987). The rate of glucose synthesis in sheep is lowest at maintenance or below maintenance levels of feeding and highest in late pregnancy and early lactation (Figure 2.4).

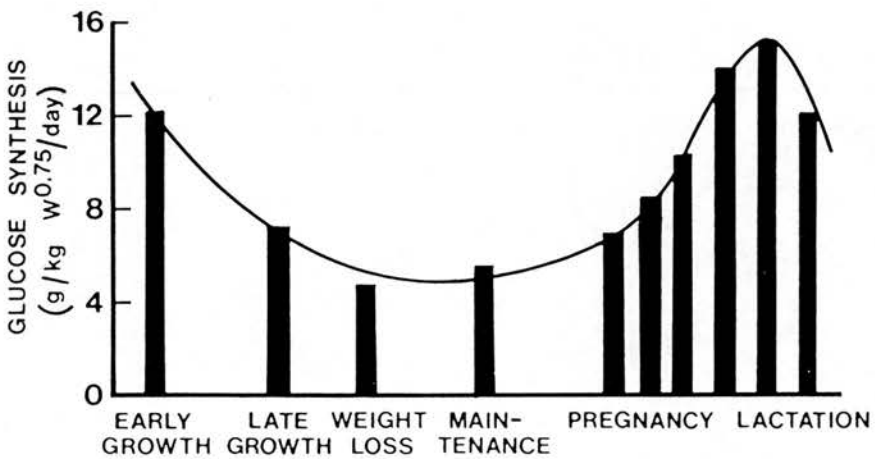
Table 2.2. Maximum Contribution (%) of Circulating and Endogenous Metabolites to Oxidation in Skeletal Muscle of the Hind Limb of Fed Sheep during Sustained Exercise (Pethick, 1984)

METABOLITE	Duration of Exercise		
	15min	60min	120min
Acetate	8	8	8
Ketone Bodies	2	4	4
FFA	15	26	40
Glucose*	21	25	29
Endogenous substances in muscle	54	37	19

* corrected for lactate uptake and output.

In a working cow glucose and free fatty acids are likely to be in high demand for work and milk production. Amino acids may be channelled into glucose production if the requirement for glucose synthesis takes precedence over other metabolic functions. Jarrett *et al* (1976) consider that in fed non-lactating sheep, approximately 0.60 of the glucose carbon taken up by muscle is returned to the blood as lactate and that if allowance is made for some pyruvate and alanine release, it is unlikely that significant amounts of glucose are oxidised. Under normal fed conditions, propionate is the main precursor of glucose, and if all propionate

Figure 2.4. Rate of glucose synthesis according to productive state in sheep (Preston and Leng, 1987)



produced in the rumen is used for glucose synthesis this could meet the normal entry rates (Leng, 1970).

In comparisons of non-lactating and lactating sheep, in which close similarities appear to exist with the situation in cattle, Pethick and Lindsay (1982a) have indicated a direct competition between the mammary gland and skeletal muscle for acetate. Normal lactation was associated with a reduced extraction by muscle and the 'spared' acetate was comparable to that removed by the udder. In the muscle of non-lactating ewes glucose accounted for 0.57 of O_2 utilised. In lactating ewes this fell to 0.32 due to the increased need for lactate synthesis.

In pregnancy and lactation there is therefore apparently a reduced utilisation of glucose by skeletal muscle. The lactating mammary gland and the pregnant uterus use a high proportion of the available glucose in ruminants and the hormonal balance appears to conserve glucose for this purpose (Leng, 1985).

The pathways of metabolism of energy for muscle metabolism from dietary sources through digestion and to the blood were summarised by Ffoulkes, Bamualim and Panggabean (1987) and are shown in Figure 2.5 and a summary of metablite supply to resting and working muscle is shown in Figure 2.6.

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Figure 2.5. Pathways of metabolism of energy (ATP)-yielding nutrients for sustained muscular activity in ruminants (Ffoulkes *et al*, 1987)

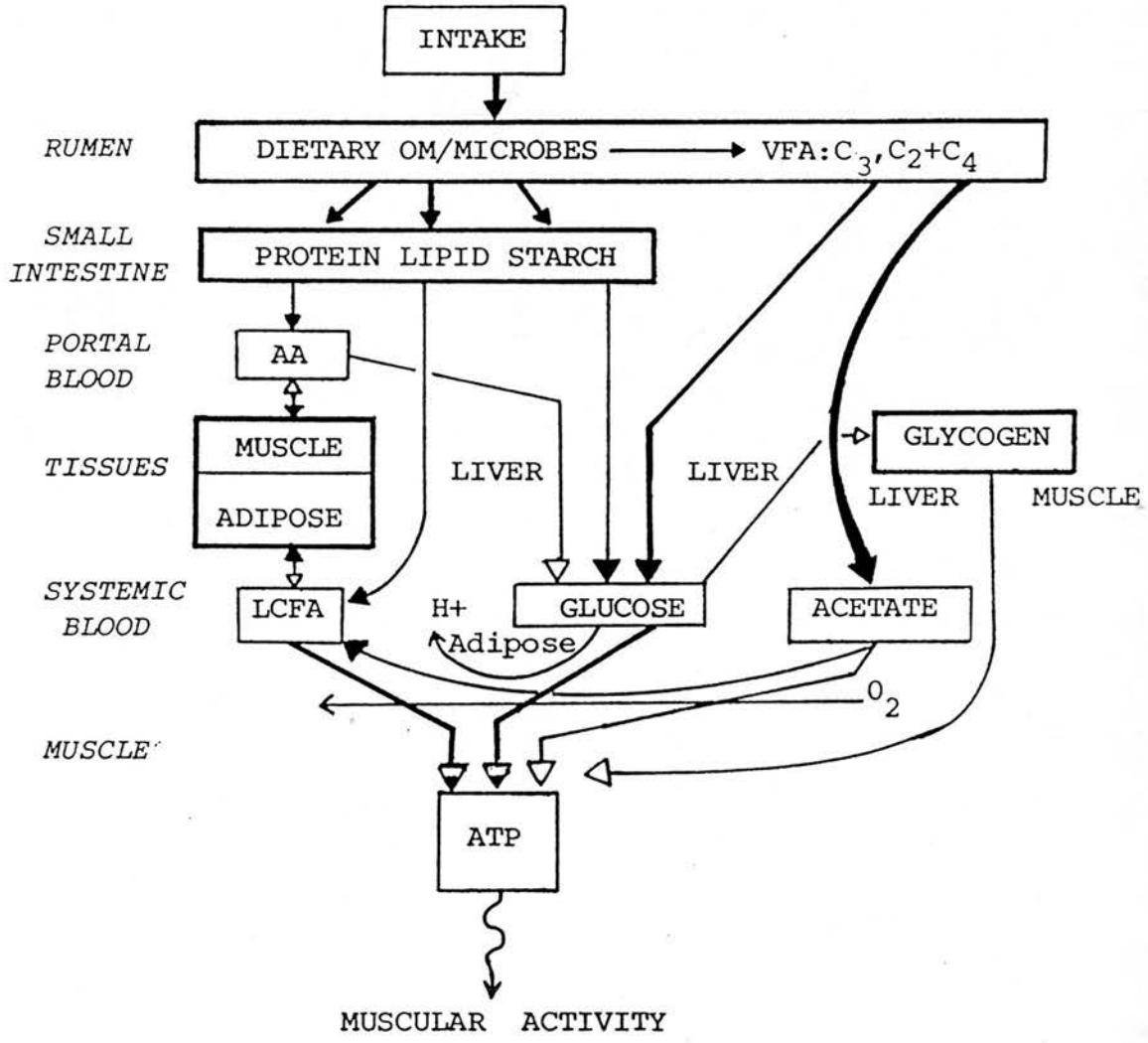
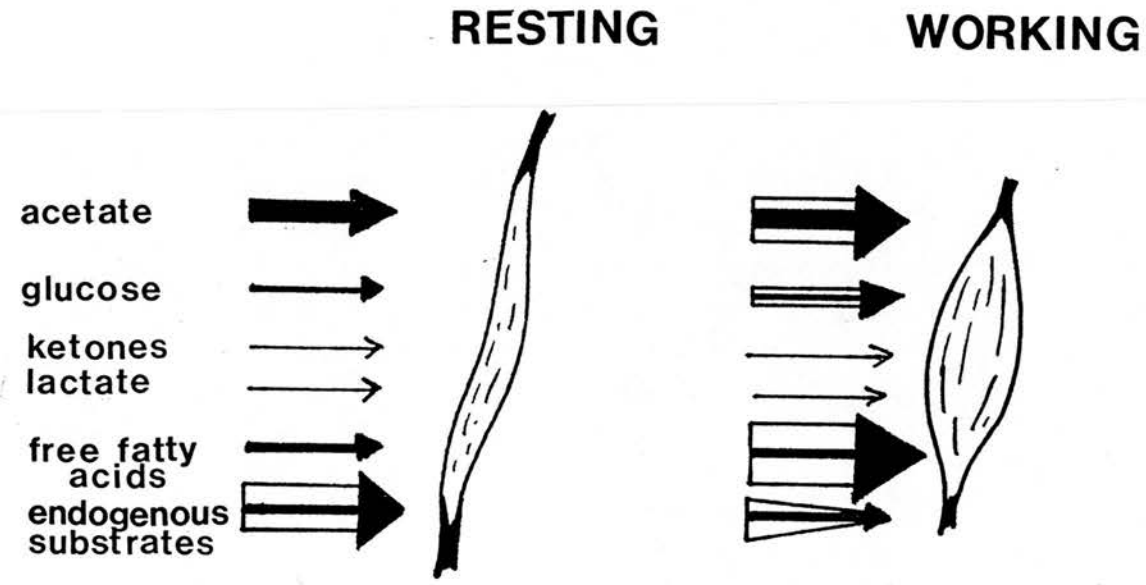


Figure 2.6. Summary of the relative change in metabolite supply in resting and working muscle



2.5.2. SUBSTRATES FOR LACTATION

The main precursors for milk are glucose, acetate, β-OH butyrate, essential and non-essential amino acids and free fatty acids (as chylomicrons, serum lipo-protein, triglycerides and free fatty acids bound to albumin) (Armstrong, 1965; Rook and Thomas, 1983). Plasma triglycerides contribute directly to milk fat (Storry, 1980). The concentrations of the main substrates used by the lactating mammary gland in normal fed and starved lactating dairy cows were listed by Baird (1977) as shown in Table 2.3.

Table 2.3. Concentrations[1] of the energy yielding substrates in the blood of normal and starved lactating cows (Baird, 1977)

Metabolite	Normal Fed	Starved (Ketotic)
Glucose	2.72	1.73
Acetate*	1.50	-
FFAs	0.17	2.14
β-OH butyrate	0.42	2.86
Acetoacetate	0.04	0.80
Lactate	0.55	0.55
Pyruvate	0.05	0.03
Citrate	0.14	0.03
Glycerol*	0.02	-
Threonine	0.09	0.05
Serine	0.08	0.03
Glutamate	0.11	0.05
Glycine	0.36	0.26
Alanine	0.17	0.11
Valine	0.18	0.28
Isoleucine	0.10	0.12
Leucine	0.10	0.25

[1] Concentrations are expressed as mmol in whole blood or plasma (amino acids only). FFAs are expressed as m equivalents/ litre plasma.
* Concentration measured in arterial blood

2.5.2.1. LACTOSE SYNTHESIS

The carbohydrate economy of ruminants has long been recognised to be precarious, since they absorb little glucose from the gut though have substantial requirements (Lindsay, 1959). Glucose typically accounts for approximately 400g/kg of total substrates taken-up by the mammary gland in goats and cattle (Rook and Thomas, 1983). 600g/kg of glucose is used for lactose production and most of the lactose is derived from glucose. 100 to 200g/kg of glucose uptake is used for gland respiration. Bickerstaffe *et al* (1974) found that at least 0.85 of lactose was derived from glucose and Buckley, Herbein and Young (1982) reported that 0.73 and 0.67 of lactose C were derived from glucose in *ad libitum* fed and feed restricted lactating goats respectively.

Hardwick, Linzell and Price (1961) demonstrated the importance of glucose for lactose synthesis and milk secretion. They examined the influence of withdrawal of acetate and glucose using isolated perfused goat udders. The withdrawal of glucose produced abrupt inhibition of both lactose and milk secretion, whereas the withdrawal of acetate produced a more progressive reduction in the synthesis and secretion of all milk constituents, especially fat. Glucose was shown to be essential not only for lactose production, but also for the general secretion of milk, as an energy source for mammary function (Linzell, 1968). This supported previous evidence presented by Rook and Wood (1959) and Rook, Storry and Wheelock (1965) which suggested that glucose is the major determinant of milk yield. The rate of milk secretion appears to

be dependent on the rate of secretion of water, which is related to the osmotic properties of lactose and is proportional to the rate of secretion and synthesis of lactose (Rook and Hopwood, 1970). The relationship between lactose yield and water output in milk is linear. Since milk is maintained isotonic with blood, when lactose secretion is depressed the output of water in milk is also depressed. The rate of secretion of lactose is also related to the secretion of protein, but occurs more independently of milk fat secretion.

2.5.2.2. MILK FAT SYNTHESIS

In the non-lactating ruminant, adipose tissue is the only important site of fatty acid synthesis (Vernon, 1981). In the lactating ruminant there are large net extractions from the plasma by the mammary gland of low density lipoproteins, chylomicra, acetate and β-OH butyrate, but little or no arterio-venous difference of sterols, phospholipids, free glycerol and free fatty acids (Linzell, 1968). The dietary factors which affect milk fat synthesis have been extensively reviewed by Storry (1980) and Sutton (1980). Milk fat is derived from acetate and β-OH butyrate from the rumen (and to a smaller extent from the caecum), free fatty acids from the small intestine and free fatty acids and acetate from endogenous sources. Diet can affect milk fat secretion directly by affecting the amounts of the precursors absorbed and indirectly by supplying other nutrients and compounds that modify the way these precursors are metabolised (Sutton, 1980).

Acetate is the principal carbon source for fatty acid synthesis in the mammary gland (Bickerstaffe, Annison and Linzell, 1974; Moore and Christie, 1981). 0.40 of milk fatty acids are derived from acetate, 0.10 from butyrate and 0.50 from blood plasma triglycerides (Storry, 1980). Short-chain acids (4-10C) represent 0.10 by weight of milk fat synthesised in the gland from acetate and butyrate, whereas 18C atoms (about 0.40 by weight) are derived from blood plasma triglycerides. 12-16C atoms (0.50 by weight) are derived from both these sources. These relationships as presented by Storry (1980) are illustrated in Figure 2.7 and pathways of free fatty acid supply from the rumen and small intestine to muscle, adipose tissue, the liver and the mammary gland are shown in Figure 2.8.

Only negligible quantities of glucose are converted to fatty acids in the mammary gland of cattle, sheep and goats, despite the sizeable uptake of glucose by the gland (Hardwick, Linzell and Mepham, 1963; Rook and Thomas, 1983; Sutton, 1980; Forsberg, Baldwin and Smith, 1985). This was demonstrated by earlier studies using ^{14}C acetate in lactating goats carried out by Popjak, French and Folley (1951) and Popjak, French, Hunter and Martin (1951). These authors considered that their results were consistent with the view that all milk fatty acids up to and including palmitic (C15) are formed by the stepwise elongation of a shorter acid by the addition of a C_2 compound derived from acetate. This differs with the situation in monogastrics. Balmain, Folley and Glascock (1954) demonstrated that in the rat 0.38 and 0.62 of fatty acid C in the mammary gland was derived from acetate and glucose

Figure 2.7. The origin of milk triglycerides (Storry, 1980)

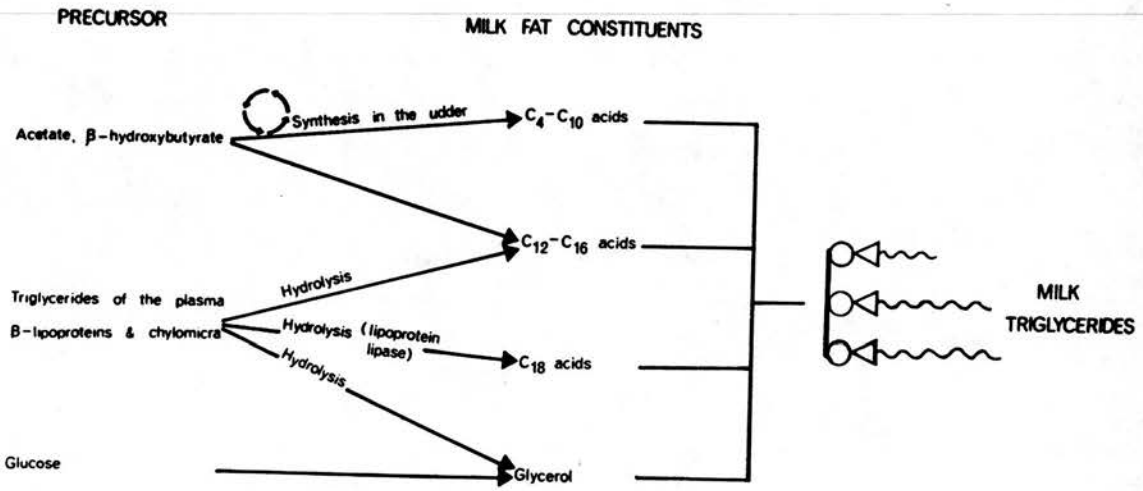
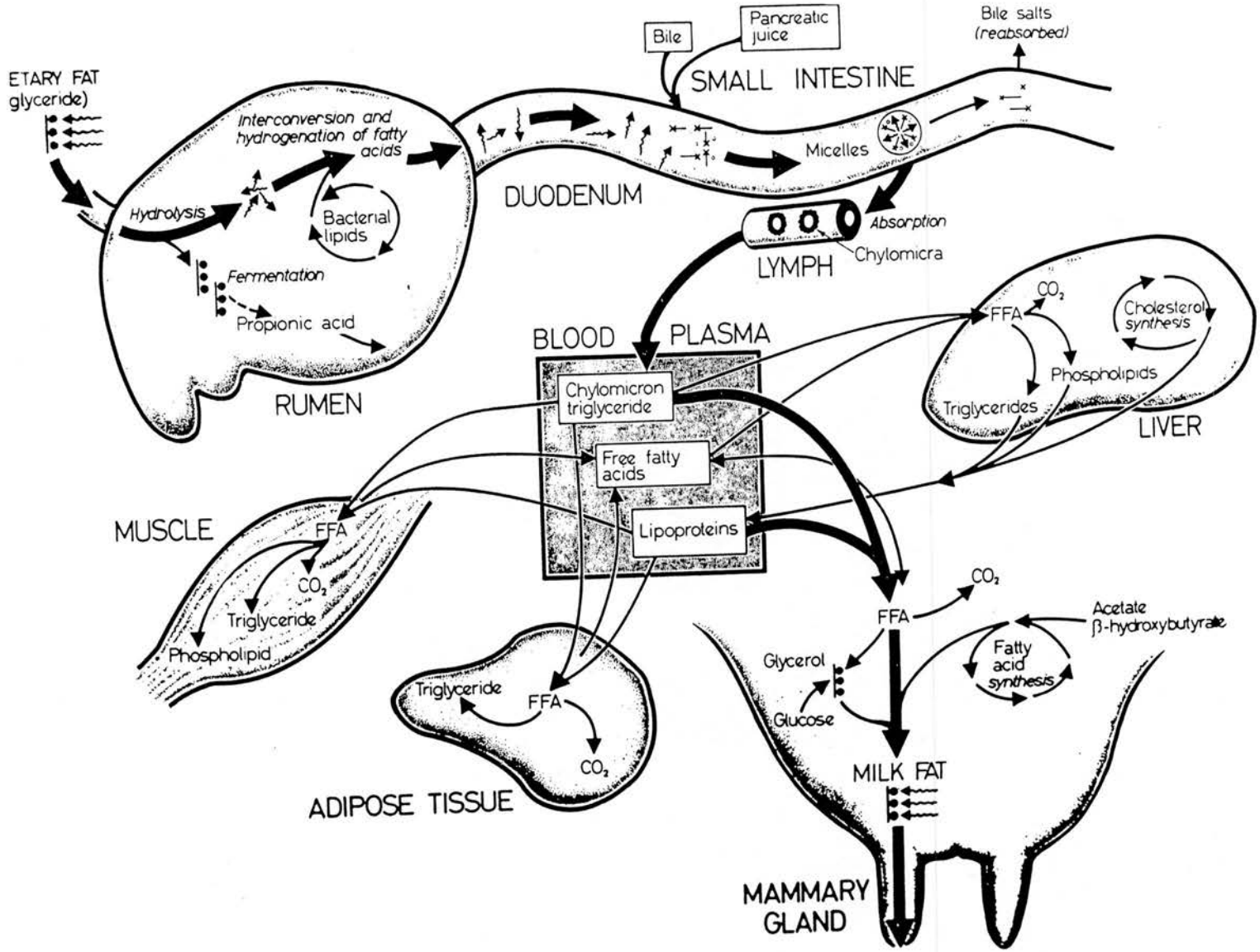


Figure 2.8. Digestion and use of dietary fat in relation to milk secretion (Storry, 1980)



respectively compared with corresponding values of 0.97 and 0.03 for sheep. In the goat about half the acetate taken-up by the udder is oxidised and the remainder of it and β-OH butyrate are extensively used to form milk fatty acids up to chain length C-14 and part of C-16 (Linzell, 1968).

The use of acetate as the major source for milk fatty acid synthesis and synthesis in general in ruminants (Vernon, 1981), spares glucose for other functions. Since most glucose in ruminants is derived from glucogenesis, it is in the interests of ruminants to 'spare' glucose where possible (Vernon, 1981). By restricting glucogenesis to the liver and fatty acid synthesis to adipose tissue (and the mammary gland), ruminants also eliminate the competition within a tissue for carbon, reducing equivalents and energy (Ballard, Hanson and Kronfeld, 1969).

2.5.2.3. MILK PROTEIN SYNTHESIS

The main nitrogen constituents of milk are α, β and k casein, α lactalbumin and β lactoglobulin which are synthesised in the mammary gland, and seroproteins and non-protein nitrogen (mainly urea) from the blood (Thomas, 1980).

The uptake by the udder of all essential amino acids is considered sufficient to account for the corresponding amino acid residues in milk protein (Mepham and Linzell, 1967). This applies also to some non-essential amino acids, while others (eg. serine and alanine) are taken up in insufficient quantities and must be partly synthesised in the tissues. Dietary protein supply can

affect the rate of milk protein synthesis and this will be discussed in greater detail in Section 2.6.4.

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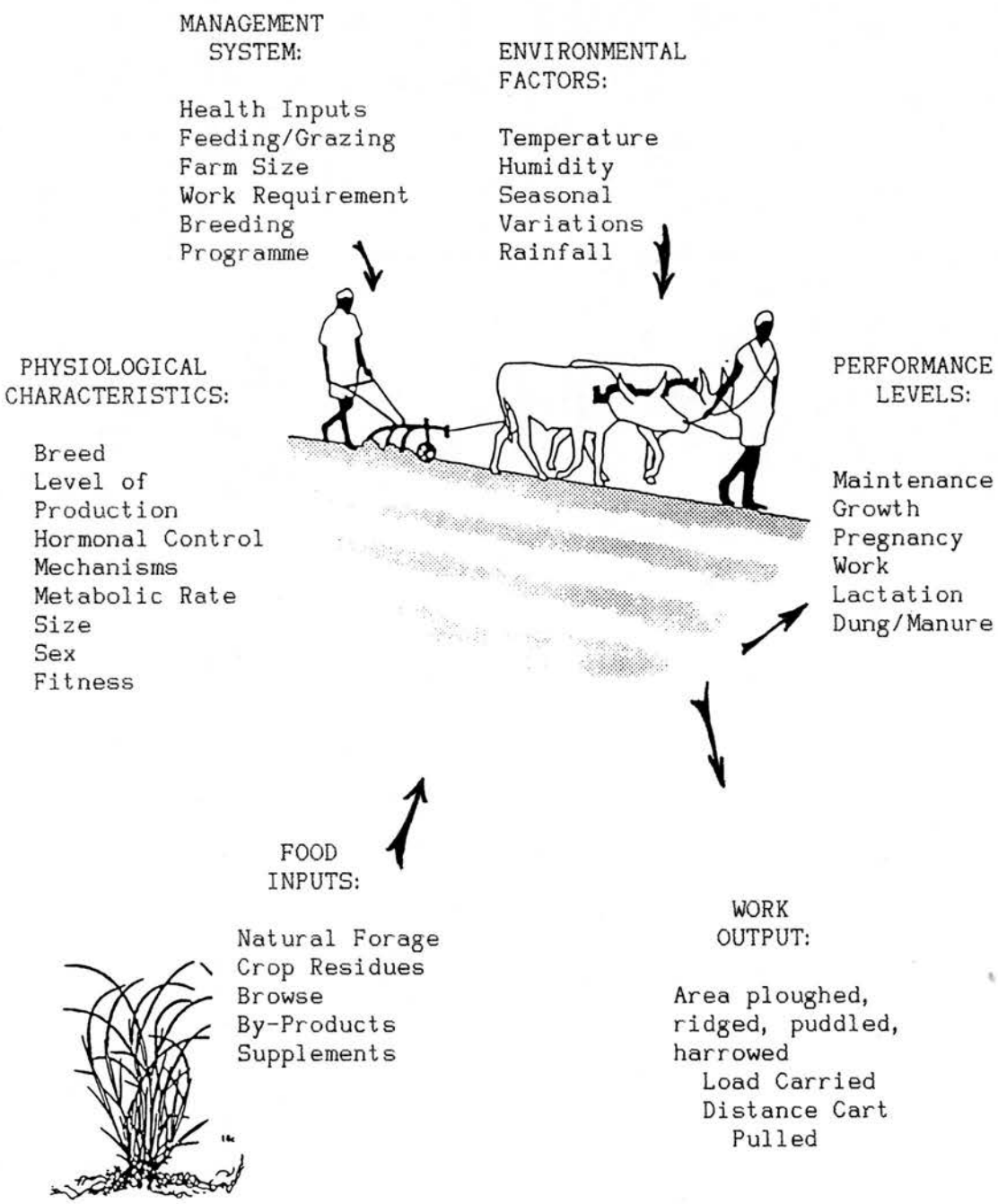
2.6. FACTORS WHICH INFLUENCE LACTATIONAL PERFORMANCE

Many variables influence lactation, including management, level of production, nutritional status, physiological condition, environmental conditions and health status and the influence of some of these have been reviewed recently by Oldham and Friggens (1989). These factors interact with metabolic controlling factors and hormonal balance to control milk production (Brockman, 1978; Bines and Hart, 1982). Environment also plays an important role in tropical draught cows and the influence of environmental factors, including the influence of high ambient temperatures on lactational performance, have been reviewed by Johnson (1965), Thompson (1973) and Parker (1984). The interactions between these factors are complex, and in the present review, only factors which relate to nutrition and exercise will be considered in greater detail. Some of the factors which influence the overall productivity of draught cows in the tropics are summarised in Figure 2.9.

2.6.1. VOLUNTARY FOOD INTAKE

For animals of given weights, the factors which control food intake have been reviewed by Balch and Campling (1962) and Allison (1985). Provided that the physical and chemical properties of food do not impose limitations to intake, ruminants can adjust intake to meet requirements in a similar way to monogastric animals (Forbes, 1983). Hence the animal's growth and lactational drive and its current physiological state play a part in determining

Figure 2.9. Some factors which influence draught cow productivity



feed intake. On roughage diets however, voluntary feed intake (VFI) is related to the amount of digesta in the reticulo-rumen and the rate of passage of digesta through the tract. For diets containing more concentrate, VFI is limited by other factors, and mechanisms may include thermostatic and chemostatic regulation. The concentrations of blood metabolites such as glucose, acetate and ketones may contribute to this control. Type and amounts of supplementation also may affect intake.

It has been demonstrated for numerous types of ruminant animal in different physiological states that an increase in energy demand can stimulate an increase in energy supply by increased feed intake. Studies with lactating cattle (Hutton, 1963) and pregnant and lactating sheep (Hadjipieris and Holmes, 1966) receiving roughage diets indicated increases in roughage intake of 0.50 to 0.70 according to physiological status and energy requirement. In dry sheep, hay intake was 780g digestible organic matter (DOM/d) and this increased steadily with the addition of dried grass cubes, so that with dried grass alone VFI was 1140g. Pregnant ewes showed similar intakes, but with ewes carrying twins and triplets a slight decrease was observed. Lambing and ensuing lactation resulted in an immediate increase in intake.

Diet composition also can influence digestion and food intake. Fadel, Udén and Robinson (1987) investigated the effect of nitrogen and energy supplements on *ad libitum* intake and digestion of oat-straw by non-lactating dairy cows and found that cows fed a fishmeal/maize gluten meal ration had increased neutral detergent

fibre intake and digestion compared with cows on either urea/molasses/starch, casein, or a urea control ration. Oldham, Fulford and Napper (1981) found that DM digestibility was higher in cows in early lactation at higher levels of CP inclusion (163 gCP/kgDM compared with 123g), but that source of CP had no effect.

Other authors have found no effect on DMI of dietary CP concentration. Robinson, McHattie, Cortes and Thompson (1979) found no effect on DMI in lactating ewes of changing from a high to a low (week 3 of lactation) and back to a high concentration of dietary CP (white fish meal). Similarly, Cowan, Robinson, McHattie and Pennie (1981) found no significant effect on DMI (*ad libitum* hay) in lactating ewes on high and low protein diets.

2.6.2. DIET COMPOSITION

Rumen volatile fatty acid concentrations may be affected by diet and the supply of glucose precursors and degradable protein may be favourably or adversely affected. Annison, Bickerstaffe and Linzell (1974) studied the effect of changing to a high starch/low roughage diet in two Friesian and two Jersey cows which had been prepared for udder arterio-venous difference measurement and whole-body milk precursor turnover estimation. In the two Friesian animals, fat concentrations were lower on the high starch diet, but fell only slightly in one Jersey cow and rumen VFA levels increased in the two Friesians and one Jersey. Rumen acetate levels remained the same, but propionate doubled. Glucose entry rates increased (due to increased propionate production) and the contribution of glucose to total body CO_2 production increased.

There were also significant falls in blood concentrations of acetate and β-OH butyrate.

A number of factors may influence the supply of glucose and glucose precursors from the gut. Carbohydrate is extensively fermented in the rumen (usually more than 0.90) (McDonald, Edwards and Greenhalgh, 1980), but on rations rich in barley and ground maize, moderate amounts of starch may escape fermentation to be absorbed as glucose in the small intestine (Lindsay, 1970; Beever, Coehlo Da Silva and Armstrong, 1970; Sutton, 1985). Uncooked ground maize is less well fermented in the rumen and with 0.80 ground maize in the diet up to 100g/d (0.18) of glucose escapes fermentation (in sheep) and up to 600g/d (0.25) in cattle (Lindsay, 1970). Under these circumstances, this is a significant contribution to glucose via the small intestine. Similar results were presented by Beever *et al*, (1970) using four sheep with duodenal and ileal re-entrant canulas and fed either dried grass and ground maize or dried grass and flaked maize. Significantly greater quantities of starch entered the small intestine on the ground maize compared with the flaked maize diet.

2.6.3. DIETARY PROTEIN SUPPLY

Both the quantity and quality of dietary protein influence milk yield and nitrogen output in milk in sheep and cattle. In addition, the partition of dietary nutrients between milk and body tissues in lactating ruminants depends on the protein/energy ratio of the diet.

At given levels of energy intake, milk yield increases with

increases in digestible crude protein intake (Thomas, 1980; Oldham and Smith, 1982). The greater the undegradable protein, the greater the response. A series of experiments have been carried out over the past decade which have further illuminated this relationship. When ewes in negative energy balance were fed different levels (0.10, 0.14 and 0.17) of a protein supplement (based on soya meal) at fixed levels of energy intake, daily mean milk yields for each group were 2.4, 2.9 and 3.1Kg/d, but no significant effects on milk composition accompanied these differences (Robinson, Fraser, Gill and McHattie, 1974). In a further study, Robinson, McHattie, Cortes and Thompson (1979) found that milk yields decreased (0.17) in ewes when fishmeal was replaced with barley in the diet and increased when this was reversed. Milk nitrogen output (g/d) decreased by 0.23 and milk fat also decreased as did the plasma concentrations of free fatty acids and urea. All levels were restored when animals returned to fishmeal diets. The responses were rapid and a subsequent experiment indicated that levels would return to normal if fishmeal was re-introduced after a short period (10 days), but not after a longer period (20 days). On low protein concentration diets (barley), milk yield was limited by the quantity of amino acids available from the diet and even in the short term the plasma pool of free amino acid N was not depleted to sustain production.

Oldham, Fulford and Napper (1981) not only investigated the effects of source of CP, but also the level of inclusion in the diet by preparing iso-nitrogenous rations containing urea, soya

bean meal, formaldehyde treated soya meal and fishmeal. These nitrogen sources were compared at four different levels to produce rations containing 103, 123, 143 and 163 gCP/kgDM. Milk yield, fat corrected milk and milk protein output all increased significantly as ration CP increased, most between 103 and 123 gCP/kgDM. These were lowest with urea and highest with fishmeal. Milk protein yield was significantly greater with fishmeal than with other sources.

The influence of the quality (in particular the ability of the protein to supply amino acids to the duodenum) of dietary protein on milk yield and composition, was further investigated by experiments involving seven diets by Gonzalez, Robinson, McHattie and Fraser (1982). Milk yields were 1.92Kg (basal diet), 2.08Kg (basal/urea), 2.26Kg (groundnut supplement), 2.45Kg (Soya), 2.49Kg (meat and bone meal supplement), 2.68Kg (linseed supplement), 2.84Kg (fishmeal) and 2.91 (bloodmeal). Yields of true protein were 76, 80, 104, 107, 105, 112, 136 and 125g respectively. The changes in plasma urea levels that accompanied the diets were related to the degradability of the dietary protein, with lower urea levels on diets with lower degradability. Penning, Orr and Treacher (1988) have provided further evidence that as the proportion of fishmeal increases in the diet at the expense of more degradable sources of protein, milk yields and daily milk N output also increase. Fishmeal tended also to increase milk fat and lactose concentrations in these experiments.

2.6.4. ENVIRONMENTAL TEMPERATURE

High ambient temperatures can affect production in numerous ways including the depression of VFI (Wayman, Johnson, Merilan and Berry, 1962), the depression of milk yield independently of reduced VFI (Johnson, Wayman, Kibler, Ragsdale, Berry and Merilan, 1961), by influencing the rate of passage of digesta (Cakala, 1965; Attebery and Johnson, 1969) the ratio of rumen VFAs (Weldy, McDowell, van Soest and Bond, 1964; Kelley, Martz and Johnson, 1967), protein catabolism (Vercoe, 1969), growth hormone levels (Mitra, Christison and Johnson, 1972) and thyroxine levels (Thompson, Johnston, Breidenstein, Guidry, Banerjee and Burnett, 1963). These factors are only noted here and detailed discussion is not given, but for cows working in hot climates, the environmental influences would require investigation. High ambient temperatures also affect the working animal's ability to lose heat and this may be a further complicating factor, resulting from the competition for blood flow between working muscle, lactation and peripheral skin for heat loss (Bell and Hales, 1985).

2.6.5. EXERCISE

2.6.5.1. THE EFFECT OF EXERCISE ON VOLUNTARY FOOD INTAKE

Light to medium work has been shown to increase voluntary feed intake in horses and rats, but the situation remains unclear in draught animals and it remains to be fully determined whether draught ruminants can increase feed intake when working (Weston, 1985).

Henning (1987) exercised sheep on treadmills to determine the effect of increased energy demand on food intake and ruminal characteristics. This experiment failed to demonstrate an increased feed intake or rumen fill with exercise levels of up to 9 km/d over three hours/d for 14 days. Henning considered that a detrimental interference with eating time was unlikely and quoted Smith (1961) who found that cattle grazing for 5h/d maintained the same intake as those grazing 10h/d. Stall-fed animals eating poor quality roughage however may respond differently to grazing animals.

Ffoulkes (1986) found a positive effect of work on food intake. In an experiment using 16 female buffaloes in Indonesia on a diet of a 1:1 mix of coursely chopped rice straw and natural pasture grass, working animals ate more than non-working animals, amounting to an increased intake of 9.8MJME. Similarly, Winngroho (1988) found a 0.25 increase in food intake in an experiment involving 16 mature female buffaloes with three exercise treatments levels which consisted of pulling an 85kg sled for 0h, 3h or 6h/d over a 39 day period. These animals were fed a 50:50 diet of *ad libitum* chopped fresh road-side grass/rice straw.

In Bangladesh, Barton (1987b) compared two pairs of bullocks over a seven week working period. One pair was fed urea treated rice straw and the other pair was fed untreated rice straw each supplemented with 1kg fresh grass. It was found that exercise did not increase dry matter intake in this experiment. The differences between the results for buffaloes and cattle is surprising, but may indicate a real difference between these two species.

2.6.5.2. THE EFFECT OF EXERCISE ON DIGESTION

Kibet and Hansen (1985) in Kenya fed 4 forages to 3 steers (2 Boran and 1 Sahiwal) which walked for 0, 1 or 10km/d to investigate the dry matter digestibility (DMD) of roughages in nylon bags suspended in the rumen. Mean digestibilities were 0.47 (0Km), 0.49 (1Km) and 0.46 (10Km). It was concluded that rumen DMD values were not influenced by distance walked.

Weston (1985) cited Ganovski (1984) who found increases of 0.11 to 0.12 organic matter and crude protein digestibility and 0.19 increase in fibre digestibility with walking 3h/d in pregnant cows and contrasted this with the work of Ellenberger and Schneider (1927) who reported small average decreases (<0.03) in overall digestibility in lactating cows.

More recently, Winngroho (1988) has reported an increase from 0.38 to 0.50 in digestibility in working buffaloes compared to non-working buffaloes. Ffoulkes (1986) also reported a 0.13 increase ($p<0.05$) in digestibility in working buffaloes which received 100% of requirement. Animals on a restricted diet (75%) showed a decrease in digestibility. This reduction in digestibility in restricted animals was in agreement with Astatke, Reed and Butterworth (1986) who found that DM digestibilities were higher in working cattle in Ethiopia fed to requirement (maintenance plus 5 hours work) than in animals on a restricted (75%) diet. DM digestibility in animals fed to requirement was 0.58 compared with 0.40 for restricted animals.

2.6.5.3. THE EFFECT OF EXERCISE ON MILK PRODUCTION

When considering the value of female animals for draught, the effect on milk production must be considered. Little study has been made of this subject. Rizwan-ul-Muqtadir, Gill, Ahmad and Ahmad (1975) conducted a study in Pakistan to determine the effect of ploughing on the yield and composition of milk in lactating buffaloes. Three lactating buffaloes were used for three hours a day for 21 days. The area ploughed averaged 0.57 acres per cow per 3 hours. This level of work caused a 0.14 reduction in milk yield. Average yields and composition before and during the work period are given in Table 2.4.

Table 2.4. The effect of work on milk yield and composition in buffaloes (Rizwan-ul-Muqtadir *et al*, 1975)

	Milk (Kg)	Fat%	SNF%	Protein%	Lactose%	Ash%
Before Work	7.1	7.3	10.03	3.56	4.95	0.72
During Work	6.1	7.3	9.97	3.53	4.86	0.84

Lawrence (1985a) worked well-fed dairy cows in Costa Rica and measured no affect on milk production. Work carried out on European dual purpose breeds (Krautforst, 1947) also showed that cows in good condition showed no drop in milk yield due to work. Similarly, Rajapurohit (1979) noted that in Egypt working neither had any ill-effect on the milk yield nor on health. Munzinger (1982) states that investigations in Senegal revealed that the weight development of Djakore calves whose mothers were used for draught and received a working ration, was significantly better

than that of calves whose mothers did not work. The apparant increased productivity of these cows can probably be explained by the fact that farmers often take greater care of working animals.

Kibria (1982) however, comments that cows used for draught in Bangladesh "do not yield the required quantity of milk". Goe (1983) also reports that on average draught cows lose 0.10 to 0.20 of their yield. Jabbar (1980) considered that on the evidence of cows working in Thailand, both fertility and milk yields are reduced by work. Tornede (1939) described the use of Red Hill cattle in parts of Germany, where they were used for work, milk and butter production. Eighty percent of Red Hill Cattle were used for work and they were considered better than lowland cattle, and lost less milk as a result of working. Light work in fact was reported to stimulate milk production, but heavy work caused a marked decrease (in some cases up to 0.80 of yield).

More comprehensive work carried out in Bangladesh using one pair of draught cows fed *ad libitum* treated rice straw and another pair fed *ad libitum* untreated rice straw, both supplemented with 1kg fresh grass and 300g concentrate per day, showed that over a five week working period these cows lost 0.40 (untreated rice straw) and 0.23 (treated) of their milk yield (Barton, 1987b).

The results of the relatively few works which have been reported on the effect of work on lactational performance show considerable uncertainty regarding the effect of work. The most conclusive results indicate losses in milk yield of between 0.14 and 0.40 depending on diet and work intensity. These results contrast with those of other authors who consider that work has

little or no effect in well fed animals. The difference in response between animals fed treated and untreated straw (Barton, 1987b) would support this view.

2.6.5.4. THE EFFECT OF EXERCISE ON BODY WEIGHT CHANGE

Loss of weight in working animals has been reported by numerous authors. Astatke *et al*, (1986) found that both feed restricted animals and animals fed to 100% of requirement lost weight (between 0.04 - 0.17) when working for 5 hours over a 23 week period. Restricted animals lost more than animals fed to requirement. Similarly, Winngroho (1988) found that working female buffaloes lost weight compared to non-working control animals. The trial lasted for 39 days and animals pulled a sled for either 0h (A), 3h (B) or 6h/d (C). Group A gained 4Kg, Group B lost 8Kg and Group C lost up to 18KG.

Ffoulkes (1986) also measured weight losses in working non-pregnant buffaloes in Indonesia. Weight changes were measured over 120 days and control animals (C) and walking animals (W) were either on a 100% (M) or a restricted (R) diet of rice straw and grass. Weight changes for CR, CM, WR and WM were +110g/d, +326g/d, -6g/d and +79g/d. These authors concluded that even on a restricted diet of rice straw and grass, non-working animals could maintain themselves and gain weight, but that working animals require a better diet to avoid weight loss. They suggested that feeding strategies involving supplementation should aim to provide nutrients that are non-fermentable, and which are digested in the

small intestine.

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2.7. ENERGY DEMANDS AND WORK OUTPUT

2.7.1. ENERGY COST OF WORK

Lawrence and Richards (1980) made 65 determinations of the energy cost of walking above standing, and found that this varies directly with the body weight (W) of the animal and logarithmically with the speed (V) of walking, such that:

$$E = 0.002WV^{1.59} .$$

Ribeiro, Brockway and Webster (1977) reported that the energy cost of horizontal locomotion was 2.1J/kgBWt/horizontal m at speeds of 45 - 80m/min, and that the energy cost of vertical locomotion was approximately 26J/kgBWt/vertical m.

Lawrence and Mathers (unpublished) state that over 14.5 days a pair of oxen (350KgBwt) would expend a total of 291 MJME/animal for work (ie. 20.1MJ/d). They state that each working day such an animal could expend 1.7 to 2.5 x maintenance energy.

Starkey (1981) states that for a 300Kg ox walking, pulling, ploughing, pulling carts or carrying backloads will require up to 27 MJME for 5 hours work (or 1.8 normal maintenance).

2.7.2. TRACTIVE EFFORT AND WORK CAPACITY

The draught work which must be performed for agricultural activities is determined by the conditions relating to arable

farming and economics. The available tractive effort of draught animals is a function of various factors. The most important is the body weight of the animals. Maximum efforts over short periods may be 4 times as great as average tractive effort (Munzinger, 1982).

Goe (1983) presented an extensive review of the status of research in animal traction. In general tractive efforts are reported to range from 0.10 to 0.14 of body weight at speeds of 2.5 to 4.0 km/h.

Chantalakhana (1981) states that swamp buffaloes such as those in Indonesia, Philippines or Thailand are used for work approximately 2 - 4 months per year. In Thailand they work most intensively during May to September involving ploughing, raking, puddling and transportation. Most Thai buffaloes work 5 hours per day and plough 4 - 5 acres per year. Buranamanas (1963) reported that on average buffaloes worked for 122 days per annum, but that the length depends on the region and farming system (ie. 66 days in the north, 146 days in the Central Plain and 138 days in the Northeast of Thailand). Buffaloes begin work at approximately 4 years and may work for 12 - 20 years.

Gill (1981) states that a typical draught bovine used in Bangladesh is rather small, generally in the range of 200 - 250 Kg in the case of bullocks and 160 - 170 Kg for cows. Their working life extends from 5 - 11 years.

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CHAPTER THREE

SUMMARY OF THE LITERATURE REVIEW AND OBJECTIVES OF THE RESEARCH PROGRAMME

3.1. SUMMARY OF THE LITERATURE REVIEW

Cows, both pregnant and lactating, are used to provide draught power in numerous countries in both tropical and temperate regions of the world. Oxen however, are usually preferred to cows, but where pressure on land and feed resources for ruminant stock is high, large male animals are often replaced by female animals. A number of examples can be cited of countries where this has happened or is happening. In these circumstances, cows can utilise energy and other feed resources more efficiently than male animals, because they produce more product per unit of maintenance requirement.

Attention has been drawn by numerous authors to the possible effect that work may have on milk production in draught cows. The opinion is divided concerning the effect of exercise on milk yield and milk composition. Some authors consider that in well fed cows work will have little of no adverse effect, whereas others are less confident that this is the case. The most conclusive research to date has indicated that work can affect milk yield by between 0.14 and 0.40 depending on diet. Attention has been drawn to the possibility that glucose supply in working cows may be an important limiting factor to milk production as a result of the competition for glucose between exercise and lactose synthesis. The effect of exercise on milk composition is also not well understood.

The diets of temperate dairy cows differ from those of tropical draught cows, in which a greater reliance is placed on crop residues, by-products, green grasses and browse. The energy yielding metabolites provided by such diets differ in quantity and type from those resulting from low roughage/high concentrate diets and diets in which a greater proportion of the components (particularly starch and amino acids) are digested in the small intestine.

Substrates available as energy sources in working, lactating cows are either derived from exogenous (dietary) or endogenous sources. The main metabolites available for lactation and muscular activity are **acetate, ketone bodies, glucose, glucose precursers** (mainly **propionate, lactate, pyruvate, glycerol** and **amino acids), free fatty acids** (and other lipid derivatives such as **triglycerides)** and **amino acids.**

The main precursers of milk are glucose, acetate, amino acids, free fatty acids, plasma triglycerides and β-OH butyrate. Acetate is produced exogenously in the rumen and lower gut and endogenously, mainly in the liver, but also in the lactating mammary gland. Levels are high in fed animals, but lower in fasting animals. 0.25 of entry rate is derived from endogenous sources in fed sheep, but 0.50 to 0.75 in fasting sheep. In fed animals, β-OH butyrate is produced in the rumen epithelium from butyrate and this source accounts for 0.80 of ketogenesis in fed animals, with only small amounts from acetate or free fatty acids (<0.05). In fed animals liver ketogenesis from butyrate which has escaped metabolism in the rumen epithelium is also significant. The

contribution of free fatty acids rises in fasted animals (0.29+), with a fall in synthesis from butyrate. Free fatty acids are catabolised in the liver.

Glucose is produced largely endogenously in the liver and kidneys from propionate (0.40 to 0.60 in fed lactating and non-lactating cows; 0.20 to 0.57 in fed sheep), glycerol, lactate, pyruvate and amino acids. The liver contributes 0.80 to 0.90 of glucose synthesis. In fed ruminants propionate is a major precursor. Some propionate is converted to lactate in the rumen epithelium. In fasting animals no propionate is produced and glycerol from body fat replaces up to 0.50 of the propionate glucose, but most may come from amino acids (mainly alanine and glutamine). Glycerol is metabolised mainly (0.80 to 0.90) in the liver and at the highest rates in fasted animals may account for 0.35 to 0.40 of glucose turnover. Lactate, pyruvate and glycerol are also important renal substrates for glucogenesis. Carbon is cycled between lactate and glucose in fed sheep and lactate may account directly for 0.15 of glucose. Under some conditions small amounts of glucose may be also absorbed from the small intestine.

Amino acids are supplied from the build-up of the rumen microbial population (which depends on the level of dietary energy and degradable nitrogen) and from dietary proteins digested in the small intestine. The absorbed amino acids may be used for glucogenesis or for replacement of tissue proteins.

Depending on the nature of the diet, free fatty acids are absorbed from the small intestine in varying amounts. Dietary glycerides are rapidly hydrogenated in the rumen to stearic acid

which passes from the rumen adsorbed on digesta.

The main energy metabolite for resting muscle in fed ruminants is acetate, with contributions from β-OH butyrate, glucose, lactate and free fatty acids. The contribution of free fatty acids increases in working muscle and when animals are starved, whereas the contribution of acetate reduces. Glucose utilisation by working skeletal muscle also increases. These metabolites have competing uses for muscle metabolism and milk synthesis which compete with maintenance requirements, tissue growth and growth of concepta. Mechanisms operate which help to 'spare' glucose for milk synthesis and foetal growth so that under normal conditions in pregnancy and lactation there is reduced utilisation of glucose by skeletal muscle. Exercise puts a further demand on metabolite supply, particularly glucose and free fatty acids. In exercising animals blood glucose levels increase in the short term as a result of glycogenolysis. In the longer term, blood glucose levels may decrease and levels of free fatty acids and β-OH butyrate increase indicating tissue mobilisation. Under these circumstances, free fatty acids become a more important energy source for maintenance and working muscle.

Lactational performance is affected by many factors and is sensitive to most environmental, physiological and metabolic changes. In the tropics high ambient temperatures may affect feed intake and the levels of some of the hormones which control milk production and energy partition. The problems of nutrient supply for lactation in cattle in temperate environments are further complicated by environmental effects in tropical conditions.

Feed intake is affected by the roughage content, ME content and nitrogen content of the food eaten. On good quality diets, food intake can increase when demand increases and intake levels usually increase at parturition and during lactation. Food intake may also increase in working animals and exercise may have a beneficial effect on nutrient digestibility. The supply of metabolites similarly is affected by diet composition and the total amount of food ingested. Glucose supply is affected by diet in a number of ways. On high roughage diets the proportion of propionate is lower than on diets with higher concentrate levels, in which the proportion of propionate increases. Some diets provide greater quantities of dietary amino acids digested in the small intestine, and these may contribute to glucogenesis. Some feed components such as ground maize produce greater quantities of starch digested in the duodenum than other feeds.

Both glucose and amino acid supply affect milk yield. Glucose is the main precursor of lactose and only negligible amounts of glucose are used for free fatty acid synthesis in the mammary gland. In monogastric animals glucose is used for milk fat synthesis, but in ruminants milk fat is formed mainly from acetate by step-wise elongation of the carbon chain. At given energy intakes, milk yield responds positively to increases in dietary undegradable protein intakes.

Exercise is primarily a drain on certain energy metabolites and the effect that such a drain has on other production functions depends on the level of exercise and the supply of energy metabolites. The condition of tha animal may influence the supply

of metabolites from endogenous sources, particularly the supply free fatty acids and lipid derivatives. It would appear that exercise partially over-rides the mechanisms which control energy partition, so that other production may suffer in the short-term.

3.2. OBJECTIVES OF THE RESEARCH PROGRAMME

Against the background of information presented in the literature review on the influence of exercise on lactational performance and the consequences of this for nutritional support, a programme of research was designed to address a number of issues. The objectives of the research-programme were as follows:

i) To investigate the effect of exercise on milk yield and milk composition in pregnant, lactating cows.

ii) To investigate the effect of exercise on body weight changes in pregnant, lactating cows.

iii) To investigate the effect of diet on the response to exercise in pregnant, lactating cows.

iv) To investigate the effect of exercise on intake of barley straw in pregnant, lactating cows.

v) To investigate the effect of dietary supplements on barley straw intake in pregnant, lactating cows.

vi) To investigate the effect of exercise on blood metabolite levels (glucose, β-OH butyrate, free fatty acids, urea, albumin, globulin, Mg and P) in pregnant, lactating cows.

The experiments which are described in Chapter Four were designed to investigate numerous aspects of the effect of exercise on lactational performance in cows. The most direct way in which exercise may affect production is by its effect on energy and nutrient use. The experiments investigated the overall effect of

execise on lactation and how the supply of energy and nutrients influence the response to exercise. The effects of quality of concentrate diets fed to requirement and concentrate supplements to straw were investigated and also the effect of exercise on intake of a poor quality roughage, barley straw.

The results of the experiments are not discussed separately, but the results from each experiment for each variable investigated are dealt with together under the appropriate heading.

The consequences of the research carried-out are discussed in the context of tropical animal production systems and the implications for draught animal management.

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METHODS AND PROCEDURES

EXPERIMENTS I, II & III

CHAPTER FOUR

METHODS AND PROCEEDURES FOR EXPERIMENTS I, II AND III

4.1. INTRODUCTION

The experiments described in Chapter Five were carried out to investigate the effect of a fixed amount of exercise on milk yield, milk composition, body weight, overall energy balance, blood metabolite levels (Experiments II and III) and voluntary intake of poor quality roughage (barley straw) (Experiment III). In addition, the effects of diet composition on these factors and on the response to exercise were measured (Experiments II and III).

In the following sections, a preliminary description is given of aspects which were common to all experiments, followed by a full description of each experiment in Sections 4.3 to 4.5.

4.2. EXPERIMENTAL DETAILS COMMON TO ALL EXPERIMENTS

4.2.1. LOCATION OF THE EXPERIMENTS

The experiments were carried out at the Edinburgh School of Agriculture's farm at Easter Howgate, located approximately six miles southwest of Edinburgh at the foot of the Pentland hills. The experiments were carried out between May and August in 1986, 1987 and 1988.

4.2.2. ANIMALS AND HOUSING

The animals used for the experiments were selected from the

Easter Howgate farm's autumn-calving herd of crossbred Hereford x Friesian beef suckler cows. These cows were managed in the same way as a commercial herd, but with the objective of producing calves for nutrition and growth trials at the farm over the following winter before sale at 18 months of age. The cows were in-wintered in a loose shed with their calves and were fed a diet consisting largely of silage supplemented with potatoes and straw. Normally the cows would be turned-out to pasture as soon as adequate grass growth had occurred in May. The calves would normally be weaned at this time and over-summered on separate pasture.

Twelve cows were required for each of the experiments. This number was manageable and allowed smaller treatment groups of four or six cows. Initially fifteen to twenty cows in their second and third lactation (Experiments I and II) or subsequent lactations (Experiment III) and confirmed pregnant and in milk with a calf at foot in May were chosen from the herd. The final selection of the twelve most suitable cows was made later. In 1988 only cows older than those used in Experiments I and II (up to sixth lactation) were available for the experiment due to a change in farm policy to the operation of a spring calving herd. The cows were on average in the 35th week (245th day) of lactation and 24th week of pregnancy at the beginning of each experimental period. Appendix 1 shows the stage of pregnancy.

At the end of each experiment the cows were returned to pasture before normal calving in September/October.

Initially it had been intended that the experiments should

be carried out at the Centre for Tropical Veterinary Medicine using either the 'Treadmill' or the 'Circular Race' which are available there. The use of either of these however, would not have allowed adequate animal replication, since only one or two animals can be used at a time on that equipment.

The farm at Easter Howgate offered a solution to these problems: i) it is ideally located near an enclosed tract of woodland suitable for sustained animal exercise; ii) a relatively large number of similar animals were available in the autumn calving herd; iii) the farm offered suitable facilities for animal housing, handling and weighing, routine milking, feed storage and slurry clearing.

The stall arrangement in the shed consisted of two rows of raised concrete stalls (Figure 4.1) backing onto a slurry channel cleared by an automatic scraper and facing a central aisle with easy access to the individual feeding bins for each cow (Figure 4.2).

4.2.3. INITIAL ADAPTATION PERIOD

The cows were removed from the main herd with their calves in the first week of May at the normal time of turning-out to grass and were introduced with their calves at random to each side of the individual feed pens of the Beef Unit.

The first treatment period of the experiment was preceeded by an adjustment period of up to 4 weeks in which animals were introduced to the experimental diet and the milking routine. Milk yields were recorded daily and body weights were recorded

Figure 4.1. The stall arrangement in the Beef Unit

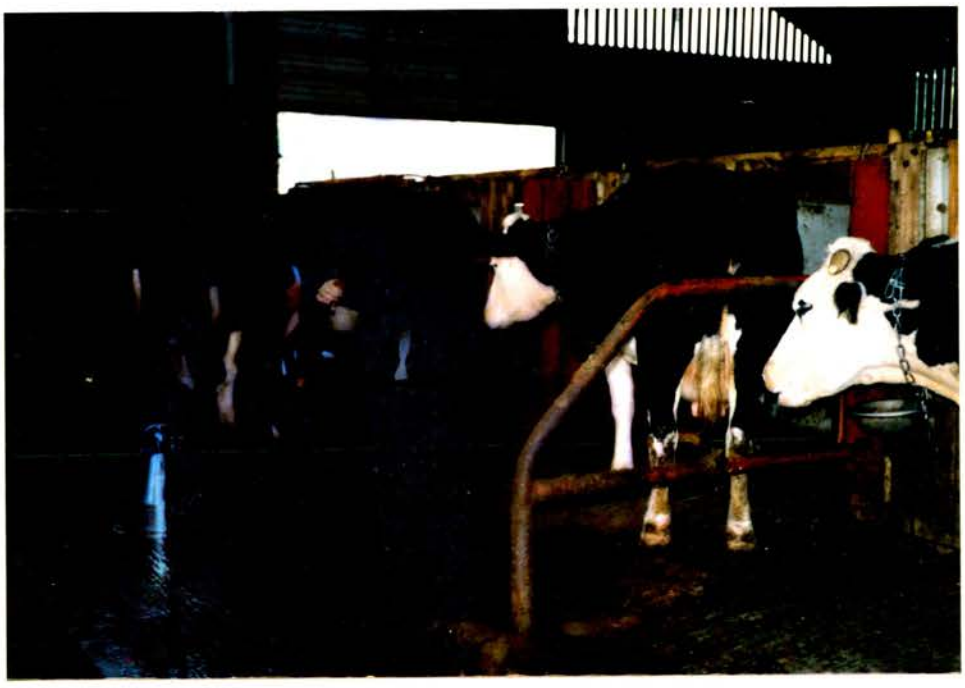


Figure 4.2. The individual feed bins in the Beef Unit

twice weekly during the adjustment period.

After introduction to the house, the cows were allowed to run freely with their calves for two days. Thereafter they were chained in the individual feeding pens and the calves were allowed free access to their dams. The cows were handled as much as possible and the stalls swept twice a day during this initial period to accustom the cows to their new housing and management.

The calves were kept with the cows for long enough to ensure that lactation continued until the cows had settled-down to a routine milking regime. After the first few days the calves were removed from the cows during the day and night and were allowed to suckle after morning and evening milking for about half an hour. By the end of the second week the most suitable twelve cows were chosen from the initial group of cows. Cows with mastitis, blind quarters, lameness, bad temperament or low milk yields were rejected.

4.2.4. FEEDING REGIME

During the first week of the adaptation period in each experiment, the animal's diets were changed gradually from silage to the experimental diet. Cows had free access to water both during confinement and when exercising.

The diets were different in each experiment. In Experiment I a high roughage diet was fed to all twelve cows. In Experiment II a second diet was introduced and fed to six cows and compared with the diet used in Experiment I which was fed to the other six cows. In Experiment III the cows were fed *ad libitum* barley

straw with one of three supplements. The detailed composition of each diet is given under the relevant section (4.3 to 4.5) for each experiment.

4.2.5. MILKING REGIME

In Experiment I the cows had not previously been machine milked. A twice daily routine was adopted with milking at eleven/thirteen hour intervals (07.00 and 18.00h). The full working day therefore lasted from 06.30 to approximately 20.30h. Milking was carried out using a portable bucket machine with one unit (Figure 4.3) and took an average of two hours at each milking. The same routine was used throughout each experiment. The milking was divided between two milkers alternating between opposite sides of the barn (the animals were in two groups of six animals on each side of the barn) and morning and evening on a weekly basis. While one person was milking the other person recorded milk yields, sampled milk and weighed out the next day's feed.

When animals were walking, the organisation of labour was difficult, since very often only two people were available for milking and walking the animals. Weighing animals, blood sampling in Experiments II and III, weighing of food and straw and drying food samples also had to be carried out during the working day. Miscellaneous, usually unpaid, help was received for support milking and walking.

Figure 4.3. Single unit milking machine used to milk cows in each experiment

Figure 4.4. Herding cows

4.2.6. EXERCISE REGIME

The exercise treatment for each experiment consisted of walking a fixed distance for up to five consecutive days over a 21 day period with a rest period of two days between each five day period. Animals were walked on Monday to Friday (walking days), but not on Saturday and Sunday (non-walking days). Walking began on a Wednesday in Experiment I and animals walked for 15 days over the following 21 days before the groups were crossed-over. Only two complete five day walking periods were completed in Experiment I in each period. In Experiments II and III walking commenced on a Monday and three full walking periods of five days each were completed.

Lawrence (1985a) also walked a group of animals round a hill circuit in Costa Rica to simulate energy expenditure for work in draught animals. Walking uphill requires a considerably greater energy expenditure per unit time than walking on the flat and is therefore the preferred method. Walking horizontally requires approximately 2J/kg liveweight/m moved compared with approximately 26J/kg liveweight/m climbed (Ribeiro *et al*, 1977). As a result of the lack of adequate information on which to base more detailed estimations, walking downhill is considered to be similar to walking on the level in terms of energy demands. Although the animal has potential energy which must be dissipated during the descent, any braking necessary will increase the energy cost.

The animals in the present experiments were walked in groups

of six (Experiment I) or twelve (Experiments II and III) by two or more herders (Figure 4.4). The total distance walked per day was 8.8 to 10.6km and the height climbed was 400 to 480m. This was achieved by walking the cows ten to twelve times up and down a circuit which consisted of walking uphill 440 m and back along the same track to the bottom of the hill.

The height climbed was 40 m/circuit. This was measured using an RDS tacheometer borrowed from the Geography Department of the University of Edinburgh. The distance up the slope of the circuit was measured as multiples of a forty metre measuring string. The circuit is shown diagramatically in Figure 4.5. and an impression of the actual slope can be gained from Figures 4.6 and 4.7.

4.2.7. DATA RECORDING

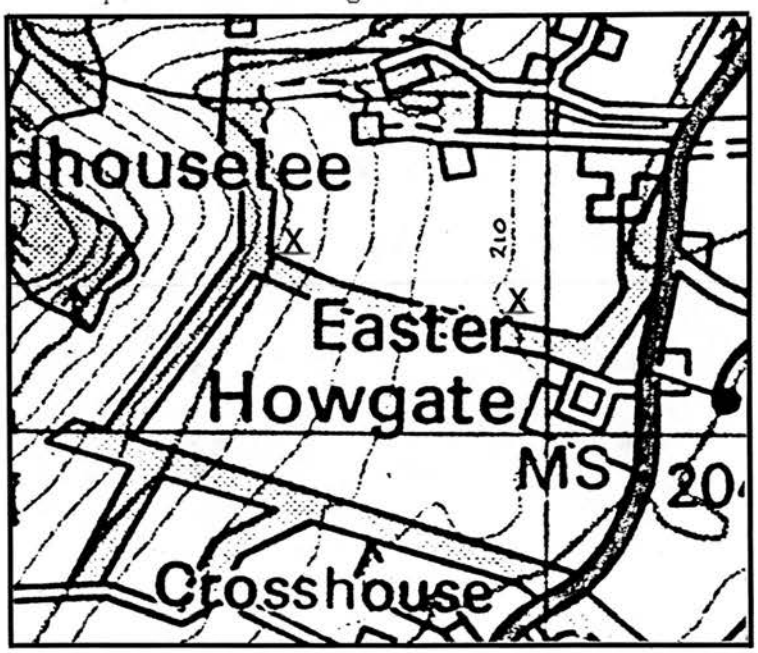
4.2.7.1. MILK YIELD

A standard milk recording sheet was used in each experiment which also incorporated the milk sample number for composition analysis. Milk was weighed on a spring balance and the yield recorded in kilograms.

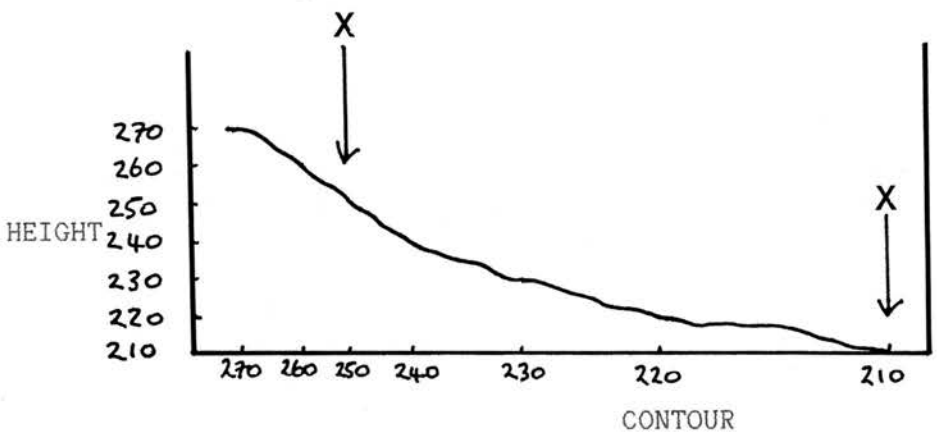
Milk yields were recorded twice a day for all cows, for all periods and for all experiments without exception. There were no missing values for milk yield. One cow (in Experiment II) refused part of her food on two consecutive days due to a faulty water dispenser and her milk yield possibly suffered as a result. It was difficult to estimate the extent of this effect

Figure 4.5. Map showing Easter Howgate Farm and the tract of woodland between contours 210 m and 250 m above sea level where the animals walked and a diagram of the circuit showing contours and height climbed

A. Map of Easter Howgate Farm



B. Diagram of the circuit



The horizontal distance between contours 210 and 250 was 400m

Figure 4.6. View from the east of the tract of woodland where the cows walked

Figure 4.7. View from the west of the tract of woodland where the cows walked

and no adjustment was made.

4.2.7.2. MILK SAMPLING AND ANALYSIS

A morning and evening milk sample was taken for each cow at each milking each day in Experiment I, but in Experiments II and III milk samples were only collected on Mondays, Wednesdays, Fridays and Sundays.

The milk was mixed thoroughly by tipping from one bucket to another. A number of methods were tried, but finally the method of tipping the milk six times between two buckets was adopted as being the most efficient and constant between samplers.

This was one possible source of error which arose during the first week of Experiment I. It was realised that simply stirring the milk before sampling might lead to a high fat content in the sample. Subsequently milk was poured from bucket to bucket six times to ensure proper mixing. Since the effect of this sampling technique on the milk composition results could not be quantified, no compensation could be made for this possible source of error in the first week of Experiment I.

Milk samples were taken in a small plastic bottle. A tablet of potassium dichromate was added to each bottle as a preservative and all samples were refrigerated before being sent for analysis.

In Experiment I the milk was analysed for butterfat, crude protein and solids not fat in the nutrition laboratories of the Veterinary Field Station, Easter Bush. The analytical procedures used were the Kjeldahl method for nitrogen determination

and the Gerber method for fat (BSI, 1969). Total solids were determined by specific gravity and solids not fat by subtraction.

In Experiments II and III the milk was analysed for fat, protein and lactose at the West of Scotland College of Agriculture. The analysis used an infra red spectrophotometer (A/SN Foss Electric ((Denmark)), MILKO-SCAN Model 203). Fat, protein and lactose are analysed separately by this method. Carboxyl groups of the triglycerides are measured for milk fat, the NH groups of the peptides are measured for protein and the number and concentration of hydroxyl groups are measured for lactose. The instrument is calibrated using ten milk samples of varying and known concentrations of fat, protein and lactose covering the known range of concentrations in the milk samples.

Although on no occasion was a milk sample not taken from a cow, some milk samples were subsequently lost in transit to the laboratory. Missing milk sample values were estimated by taking an average of the values for the three preceeding and three subsequent days.

4.2.7.3. WEIGHT RECORDING

The cows were weighed routinely throughout the experiments. This involved unchaining the animals, walking them through a weigh bridge located in the barn, and rechaining them. This became a routine operation after the second weighing and the animals were easily handled. The cows were weighed twice a week throughout the experimental period at the same time, usually on

Monday and Thursday after morning milking. Any variation from the routine occurred because the weigh-bridge was removed temporarily from the barn by the farm staff for weighing other animals.

4.2.8. PRESENTATION OF RESULTS

The data are presented in the form of tables of means for each variable investigated. Standard errors of differences (SED) are presented for means in the tables and lettered subscripts are included to show significant differences between means in columns and rows (the same letter denotes no significant difference and different letters denote a significant difference. The statistical significance of the difference between means was determined calculating the 't' value, using the SED and difference between the means. Graphs of means are presented to show variation over experimental periods.

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4.3. EXPERIMENT I:

THE EFFECT OF EXERCISE ON MILK YIELD, MILK COMPOSITION AND BODY WEIGHT

This experiment was designed to investigate the effect of a fixed amount of exercise on milk yield, milk composition and body weight change in crossbred suckler cows in Scotland. These animals were used as a model for tropical draught cows. Notable

differences between these animals and tropical animals and the environmental conditions include the species difference (*Bos taurus* compared with *Bos indicus*) body size and body condition of these animals compared with tropical cows, environmental temperatures which are lower in Scotland and the exercise carried out, which involved walking up and down a gentle gradient in the experiment compared with both walking and pulling on the flat when animals work in most tropical farming systems. The amount of work however, is similar to that carried out in other experiments (Rizwan-ul-Muqtadir *et al*, 1975; Barton, 1987b).

4.3.1. FEEDING REGIME

In Experiment I approximately 12 kg/day of a pelleted diet (diet AA6; Figure 4.8; Table 4.1) were fed during the initial period as two feeds at morning and evening milkings. This was an over-estimate of dietary requirements in the initial period in order to ensure that cows were not fed below requirement.

AA6 is a standard diet produced by the Seafield Mill, Roslin, Midlothian. It is a high roughage (0.30 chopped barley straw) diet and provides 10.39MJME/kg DM calculated from standard feed tables (ESCA, 1982) with a DM content of approximately 0.88. Table 4.1. shows the formulation and chemical composition of AA6 as specified by the manufacturers. Feed samples were taken daily and bulked weekly for analysis (at the Centre for Tropical Veterinary Medicine) of major components (Dry Matter, Ash, Gross Energy, Neutral Detergent Fibre, Acid

Figure 4.8. Pelleted diet (AA6) Used in Experiments I and II

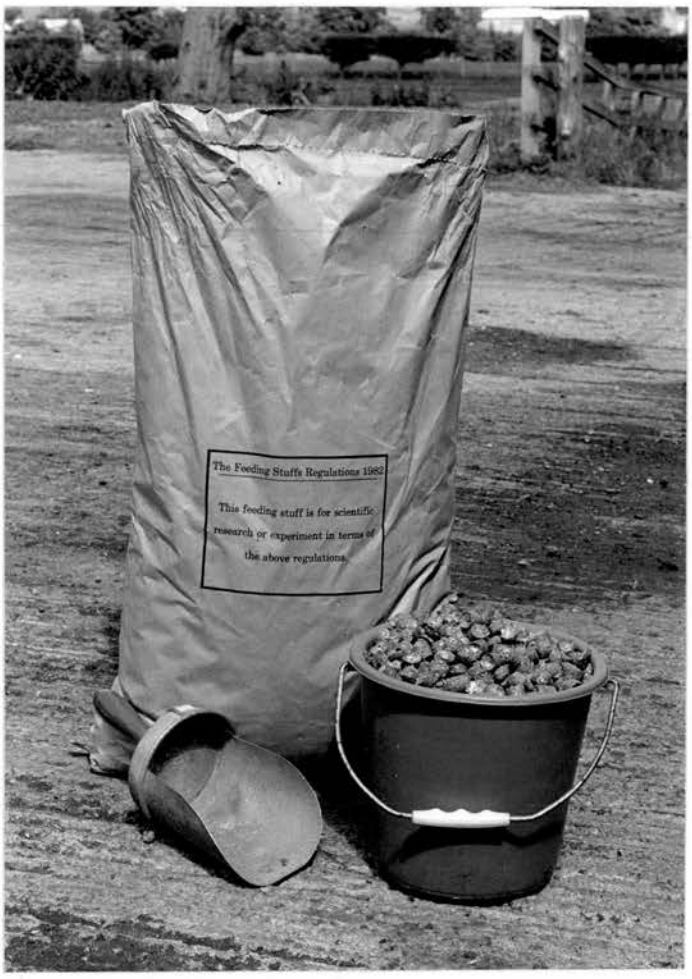


Table 4.1. Diet AA6 Composition (Manufacturer's analysis)

Ingredient	Proportion
Chopped Barley Straw	0.30
Barley	0.23
Wheatfeed	0.22
Molasses	0.10
Soya Bean Meal	0.07
Megalac (80% protected fat)	0.015
Urea	0.01
Salt	0.015
Dicalcium phosphate	0.015
Sodium bicarbonate	0.02
Limestone	0.0025
Vitamins and Trace Elements	0.0025
Ca (g/kg DM	9.6
P "	6.6
Mg "	2.8
Na "	10.0
K "	13.4
Cu (mg/kgDM)	9.0
Mn "	75.0
Zn "	51.0
Vit A (added) IU/kg	10,000.0
Vit D " "	2,000.0
Vit E " "	10.5
DM (g/kg)	880.0
CP (g/kgDM)	146.0
CF "	180.0
MAD Fibre	220.0
NDF	395.0
Starch	202.0
Sugar	71.0
EE	23.0
Ash	98.0

Detergent Fibre, Nitrogen and Ether Extract). The results of these analyses from the Nutrition Laboratory at the Centre for Tropical Veterinary Medicine are shown in Table 4.2.

Table 4.2. Diet (AA6) composition from analyses of bulked samples of the feed for the two experimental periods in Experiment I

A. Gross Energy (3 samples at beginning of experiment)

GE	=	16.95MJ/kgDM
DE = 0.663 GE	=	11.24MJ/kgDM
ME = 0.820 DE	=	9.22MJME/kgDM.

B. First analysis for bulked samples for each period

	Period I	Period II
Dry Matter (g/kg)	827.3	840.5
Crude Protein (g/kgDM)	162.5	169.9
Neutral Detergent Fibre (NDF)	397.0	401.8
Acid Detergent Fibre (ADF)	222.3	228.1
Ether Extract	4.9	5.2
Ash	99.2	95.0

C. Second analysis for bulked samples for each period

Dry Matter[1] (g/kg)	839.9	844.0
Dry Matter[2]	983.9	989.4
Crude Protein (g/kgDM)	140.3	141.0
NDF	510.4	501.8
ADF	212.5	218.5
Hemi-cellulose	297.9	283.3
Lignin	56.6	56.2
Residual Ash	10.4	9.4
Cellulose	145.5	152.9

1. Dry Matter from fresh sample.
2. Dry Matter of dried fresh sample(1.) after being ground for analysis.

In the second analysis of bulked samples the neutral detergent fibre values were higher than in the first analysis and higher than the manufacturer's specifications.

Once the experimental treatments commenced, each animal was fed an unchanged daily amount of diet AA6, calculated to meet its requirements for maintenance, pregnancy and lactation on the day prior to the start of the treatments. The basis of the daily dietary allowance was 0.5 $MJ/Kg^{0.75}$, 5MJ/Kg milk and 7MJ for growth of concepta. For an individual cow the same quantity of AA6 was fed each day for the duration of the experiment. The quantities of the diet fed to each cow each day are shown in Appendix 2A. When the animals walked they wore a mask which was intended to prevent them from eating grass while walking (Figure 4.9.). The animals were provided with drinking water when they walked and could drink through the masks (Figure 4.10.).

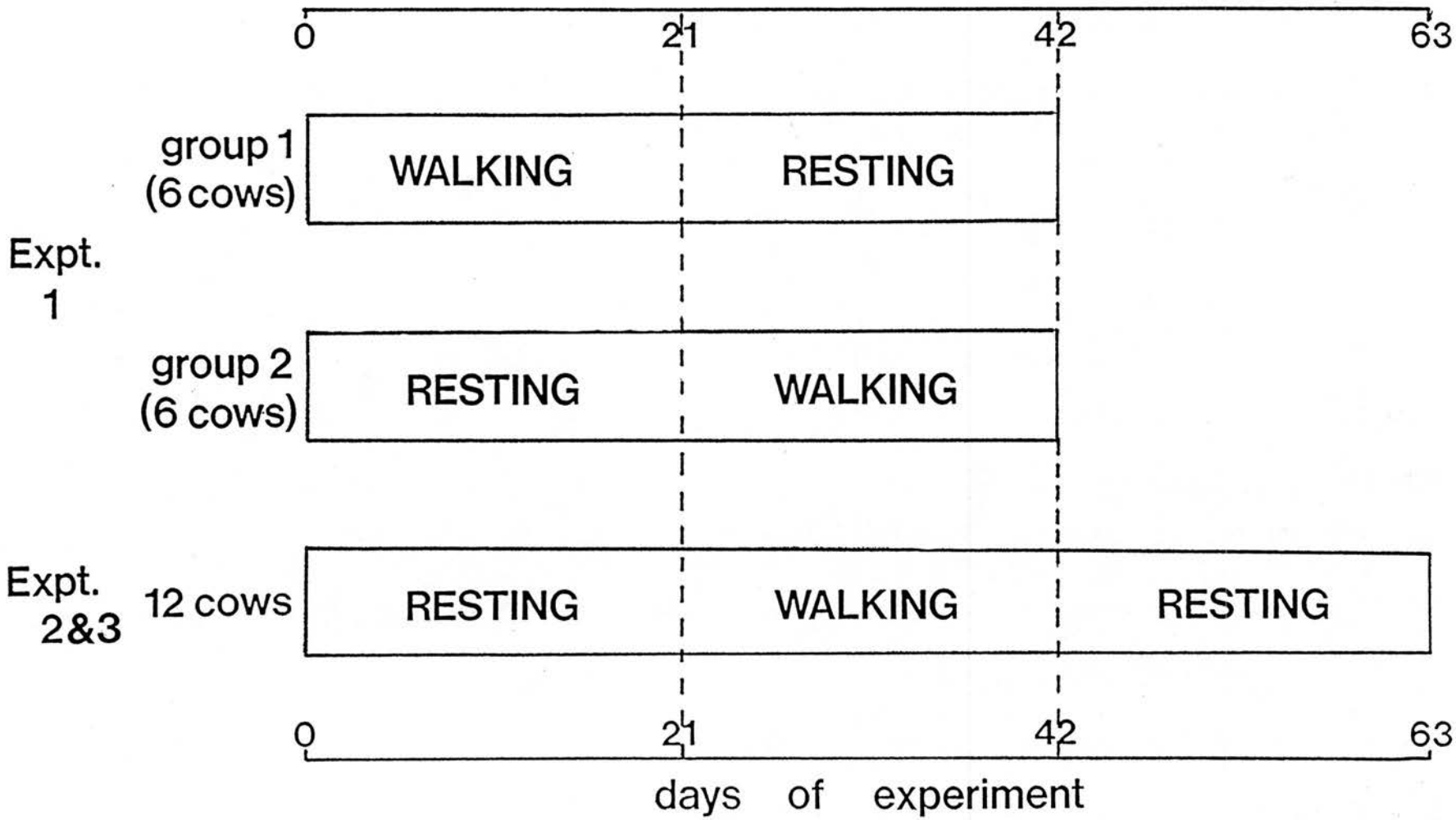
4.3.2. EXPERIMENTAL DESIGN

Experiment I had a changeover design with two groups of animals and two treatment periods of three weeks each. For the first treatment period one group (6 animals) was exercised each day (Monday to Friday) and the other group remained in their individual stalls as a control. After the first three week period, the treatments were changed over so that the six cows which walked in period one became the control group and the six control cows in period one walked in period two. The only treatment in this experiment was exercise. The experimental design is shown in Figure 4.11.

Figure 4.9. Cows wearing masks to prevent feeding when walking

Figure 4.10. Cows drinking during the exercise period

Figure 4.11. Experimental designs for Experiments I, II and III



The two groups were balanced at the beginning of the experiment for body weight and milk yield. The weights and milk yields of each cow at the beginning of the experiment are shown in Appendix 2B. The groups were balanced so that the mean body weights and mean milk yields of each experimental group were as similar as possible. While meeting this objective, the groups were also balanced as far as possible in terms of individual variation between cows so that each group had the same balance of low body weight/low yielding cows and high body weight/high yielding cows and young/low parity and old/later parity cows. In Experiment I there were two cows which had markedly lower yields than the other cows and one of these was placed in each group.

4.3.3. STATISTICAL ANALYSIS

Two types of analysis were carried out to evaluate the effect of exercise in Experiment I. Firstly a two way analysis of variance of period means was carried out for milk yield and constituents, body weights and weight changes, which partitioned variation according to exercise, period and period/exercise interaction. The analysis of variance structure is shown in Figure 4.12.

Secondly changes in milk and milk constituents yields for each treatment in each period in Experiment I were determined by regression analysis to estimate differences in the rates of decline in each period. An analysis of variance was carried out on Day 1 and Day 21 yields for each variable in each period. The regression equations are shown in Appendix 3E.

Figure 4.12. Table of Analysis of Variance for Experiment I

Source of Variation	DF	SS	MS	VR
Cow Stratum				
treatment.period	1			
Residual	10			
Total	11			
Cow *units* stratum				
treatment	1			
period	1			
Residual	10			
Total	12			
Grand Total	23			

The results are shown in tabular form in the text and graphs are shown of variables where relevant.

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4.4. EXPERIMENT II:

THE EFFECT OF TWO DIETS ON THE LACTATIONAL AND BODY WEIGHT RESPONSES TO EXERCISE AND THE EFFECT OF EXERCISE ON BLOOD METABOLITE CONCENTRATIONS

The second experiment was designed to repeat and confirm the results of Experiment I and to investigate whether a higher concentrate diet which contained a higher proportion of starch could help to overcome the effects of exercise on milk yield. Blood samples were taken from each animal once a week to investigate the effect of exercise on blood metabolite levels.

4.4.1. FEEDING REGIME

Two diets were used in Experiment II: AA6 (as in Experiment I) and a high starch diet (HS1) based on barley. The high starch diet was formulated so that the components were the same as used in diet AA6, but were included in different proportions with a considerably higher proportion of barley (Table 4.3). The high starch diet was chosen in order to determine whether a diet

Table 4.3. Comparison of the Ration Composition of Diets AA6 and HS1 fed in Experiment II

Constituent	AA6 (g/kg)	HS1
Barley Straw	300	170
Barley	230	455
Wheatfeed	220	100
Molasses	100	100
Soya	70	70
Fishmeal	-	25
Megalac(85% protected fat)	15	15
Urea	10	10
Salt	15	15
Dicalcium phosphate	15	15
Sodium bicarbonate	20	20
Limestone	2.5	2.5
Vitamins/Trace Elements	2.5	2.5
Calculated[1] M/D (MJ/kgDM)	10.39	11.29
CP (%)	14.34	15.93
CP/ME	1.41	1.42

1. ESCA (1982)

which would be expected to produce greater amounts of glucose precursors in the form of propionate from the rumen and glucose directly from small amounts of starch digested in the small

intestine would support higher levels of lactose production and higher levels of milk synthesis.

Six cows were allocated to each diet which was fed to requirement in the same way as in Experiment I. The two diets were analysed for nutrient content and the results of this analysis are shown in Table 4.4.

Table 4.4. Composition of diets AA6 and HS1 from analyses of bulked samples of feed for the three experimental periods in Experiment II

	DM[1]	DM[2]	CP	NDF	ADF	C[3]	HC[4]	L[5]	RA[6]
Diet AA6 (g/kgDM)									
Period									
I	853.1	981.6	139.6	493.1	220.9	170.2	272.2	40.4	10.3
II	846.3	980.5	142.8	480.8	225.6	174.7	255.2	42.5	8.4
III	846.3	984.3	138.7	495.9	204.0	155.8	291.9	39.5	8.7
Diet HS1 (g/kgDM)									
I	866.5	984.2	137.7	462.1	151.8	114.8	310.3	29.8	7.2
II	855.8	985.1	159.4	465.5	162.3	123.1	303.2	29.8	9.4
III	845.9	988.2	160.9	417.5	168.6	118.3	248.9	41.0	9.3

1. Dry Matter of fresh feed.
2. Dry Matter of dried sample after grinding.
3. Cellulose
4. Hemicellulose
5. Lignin
6. Residual Ash

4.4.2. BLOOD SAMPLING AND ANALYSIS

Blood samples were taken from the tail vein of each animal once a week at 14.00 hours on a Wednesday immediately after the animals had returned to their stalls after walking. When the animals returned they were brought back into the barn and rechained in their stalls. This was a routine daily operation and took less than ten minutes. Blood sampling commenced as soon as all the animals were rechained.

A new sterile needle was used for each animal and the tail vein was punctured only once and two samples taken into vacutainers from the same needle. One of the samples was taken into an ordinary vacutainer with no additional agent for serum collection and one into a vacutainer containing 14mg potassium oxalate and 17.5mg sodium fluoride to inhibit glycolytic action for glucose determination.

The blood samples were refrigerated immediately and were analysed using standard auto-analytical methods (Chemlab Instruments) in the Dalgety Dairy Health Recording Unit of the Veterinary Field Station, University of Edinburgh, Easter Bush, Midlothian. Plasma glucose concentration was estimated by a continuous flow analysis method, serum β-OH butyrate was estimated by an automated colorimetric method, plasma urea by a continuous flow analysis method, serum free fatty acids using a C-Test Kit (WAKO), total serum protein was estimated using the biuret method and inorganic phosphate and magnesium by standard continuous flow analytical methods.

4.4.3. EXPERIMENTAL DESIGN

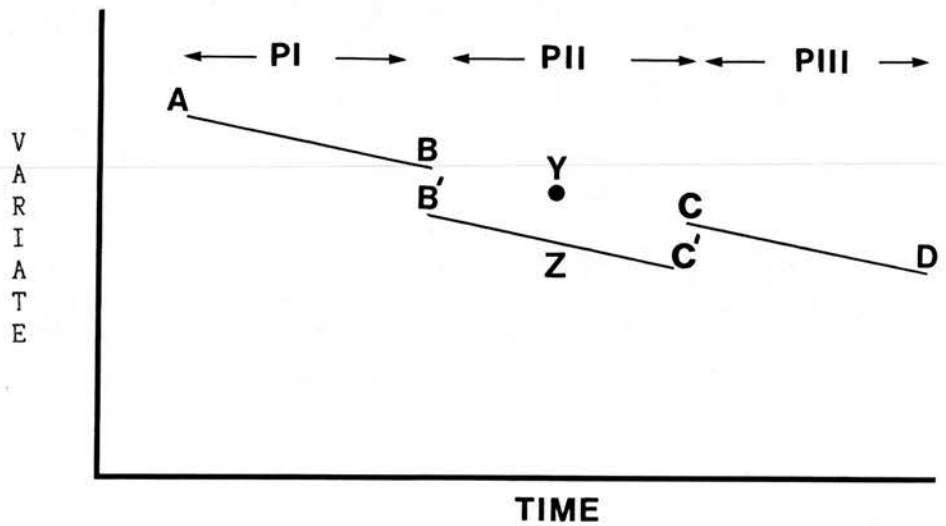
Experiment II was divided into three treatment periods of three weeks each (Figure 4.11). The first and third periods were non-walking periods in which the animals were stall-fed and milked twice daily. During the middle three week period all twelve cows walked approximately 8.8 kilometres in the Pentland Hills as described in Section 4.2.6. The walking routine and distance covered was the same as used in Experiment I, namely a total of 8.8km horizontal distance and 400m vertical distance. In this experiment animals began walking on a Monday and completed three complete 5-day walking periods.

4.4.4. STATISTICAL ANALYSIS

The data were analysed by a regression analysis of variance and by an analysis of variance of period means. The regression analysis estimated the best line of fit for all the data points of the two control periods and for all the data points of the exercise period for each cow (Figure 4.13). From these lines the regression analysis estimated the expected mid-point value (Y). This value was compared by the analysis with the actual mid-point value (Z) for the walking period. The analysis used all the data points, which took into consideration the within-cow variation.

The second method was used to compare the mean non-walking value for each cow with the mean value for each cow in the walking period (Figure 4.14). It ignored within-cow variation,

Figure 4.13. Method of estimating the expected and actual mean mid-points for the walking period for the regression analysis of varianace



Lines AB and CD are the regressions of the full non-walking data for all cows in each treatment group. Point 'Y', the expected mean mid-point for the walking period (had animals not walked), is estimated from the regression analysis for these lines.

Line B'C' is the regression of the full walking data for all cows in each treatment group. The analysis of variance compares the mid-point of this line with the expected mid-point 'Y'.

which increased the estimates of standard error. This method assumed that the mean walking and non-walking values for each cow in each period were fully representative of the daily milk yield for the cow in the walking and non-walking periods. These analyses for milk yield and milk constituent yields are shown in Appendix 3E. In the results presented in Chapter Five the differences between means are compared using the results of the regression analysis of variance described above.

Mean values from the three days prior to the beginning of the first control period were used as co-variates in the statistical analysis. In the initial adjustment period all animals were treated the same and the use of these means as co-variates allowed closer estimations to be made of the between-animal variation in milk yields and yields of constituents in this period. The use of covariates enabled some of the between-animal variation to be eliminated and reduced standard errors.

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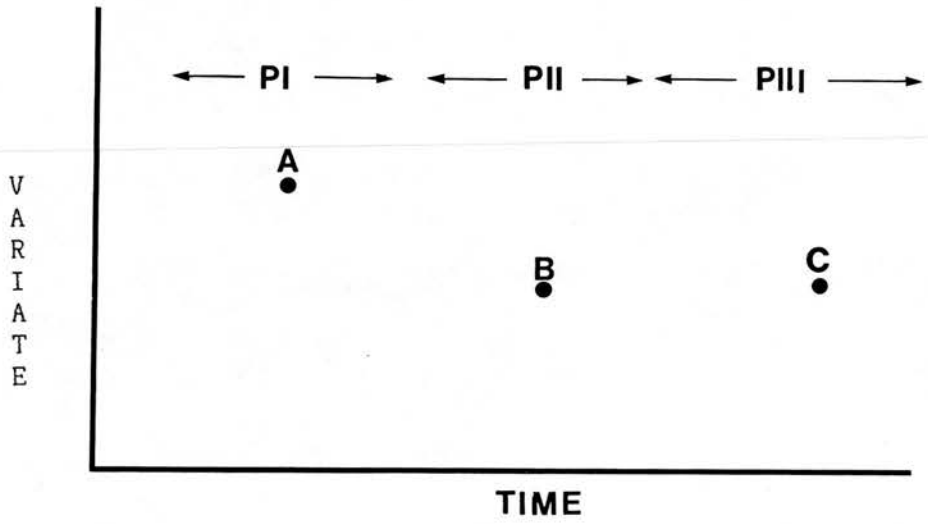
Figure 4.14. Method of statistical analysis based on period means



Points A, B and C are the means of data for each cow in each period.

4.5. EXPERIMENT III:

THE EFFECT OF THREE DIETS ON THE LACTATIONAL, BODY WEIGHT, BLOOD METABOLITE AND STRAW INTAKE RESPONSES TO EXERCISE

This experiment was designed to investigate further the effect of different diets on the lactational response to walking. In addition, animals were offered *ad libitum* access to barley straw to determine the effect of exercise on voluntary feed intake. Milk yields and body weights were measured and milk and blood samples taken as in Experiment II.

All essential details of management and experimental procedure were the same as for Experiments I and II except for the details outlined below.

In this experiment older cows were used owing to a change in farm policy to a spring calving herd. The use of older cows was not an intentional component of the experiment and could not be avoided.

The animals completed up to twelve of the circuits used in Experiments I and II and walked up to 10.6km and climbed up to 480m/d.

In addition to the blood sampling carried-out in Experiment II, sampling was also carried-out for an additional three days during the walking period. Since the animals were not exercised at weekends, it was decided to take a blood sample over a consecutive three day period consisting of a Friday, Saturday and Sunday in order to determine the duration of the response to exercise of blood metabolite concentrations.

4.5.1. FEEDING REGIME

Three different supplementary diets were offered with *ad libitum* barley straw. The animals were divided into three groups with four cows in each group: each group was offered a different dietary supplement. The diets were a high starch (maize) diet (HS2), a digestible fibre (sugar beet/urea) diet (DF) and a high protein (fish meal) diet (HP) (Table 4.5). The cows received 4kg (fresh weight) of the supplement per day in two meals of 2kg at each milking. In the adjustment period all cows received a mixture of equal proportions of the supplements.

Table 4.5. Comparison of the Ration Composition of Diets HS2, DF and HP fed in Experiment III

	DIET		
	High Protein	**Digestible Fibre**	**High Starch**
		(g/Kg)	
Soya Bean Meal	31.0	-	-
Salt	0.4	0.25	1.3
Fish Meal	30.0	-	-
Calcined Magnesite	0.5	0.5	0.5
Molasses	5.0	5.0	5.0
Mineral/Vitamins	0.3	0.3	0.3
Mollassed Beet Pulp	32.6	87.1	-
Vitamin E (10KIU/kg)	0.4	0.4	0.4
Urea	-	3.6	4.0
Dicalcium Phos.	-	3.0	2.2
Limestone	-	-	0.1
Ground Maize	-	-	43.1
Flaked Maize	-	-	43.1
ME (MJ/kgDM)	11.89	11.44	13.14
CP (%)	35.58	16.23	18.42
CP/ME	2.99	1.42	1.40

Unchopped straw was offered twice a day in the same bin in which the supplementary diet was fed. An individual daily ration of straw was weighed out each morning for each cow for the next day. The daily amount offered was adjusted to allow a 0.10 refusal each day. Half of the daily amount was offered at morning milking and half at the evening milking. It was intended that cows should have straw available at all times, but on occasion some cows ate all the straw available before the next feeding or refused less than 0.10 of that offered. If this occurred the amount was adjusted for the next day, until the refusal limit of 0.10/day was reached.

The dry matter content of the straw eaten and refused by cows on each diet supplement are shown in Table 4.6 and a full analysis of the straw and diet supplements offered in each period are shown in Table 4.7.

4.5.2. DATA RECORDING AND SAMPLING

All recording and sampling were as for the previous experiments except for straw sampling. Samples of straw offered and refused by each cow were taken each day and two bulked samples were made for each diet treatment. Offered and refused samples were dried daily for dry matter estimations and weekly bulked samples were kept for each diet for full chemical analysis. The samples were dried in metal trays at 60°C for 24 hours.

The difference in dry matter between the intake and refusals shown in Table 4.6 is due mainly to the effect of salivation

Table 4.6. Dry Matter Content (g/kg) of straw eaten and refused by cows in each dietary treatment group in Experiment III

A. Straw Intake

Diet	WEEK								
	1	2	3	4	5	6	7	8	9
HS2	855.6	872.4	870.3	845.5	857.5	867.3	861.3	854.5	859.6
DF	858.3	873.3	867.3	846.0	859.9	866.3	861.0	846.2	858.3
HP	855.8	868.4	867.8	848.7	857.7	852.9	863.3	841.4	855.1

B. Straw Refusals

Diet									
HS2	790.4	781.3	817.8	797.8	800.7	806.4	766.4	800.7	792.0
DF	800.4	777.2	813.1	801.4	785.1	796.8	779.3	808.9	782.9
HP	792.9	797.1	817.1	805.3	806.3	793.1	779.3	810.4	784.3

during eating. The straw intake was calculated daily by difference between straw offered and straw refused. This method would slightly (0.05) underestimate straw intake.

4.5.3. EXPERIMENTAL DESIGN AND STATISTICAL ANALYSIS

These were as described for Experiment II in Sections 4.4.3. and 4.4.4.

Table 4.7. Composition (%) of straw and diets HS2, DF and HP fed to animals in each period in Experiment III

%	DM	NDF	ADF	H/CELL	LIG.	CELL.	R. ASH	CP	EE	ASH
Week 3										
Straw HP	93.8	90.5	58.9	31.6	12.6	45.4	0.9	3.2	1.0	3.3
Straw HS1	93.4	90.8	59.4	31.3	11.2	46.7	1.5	3.3	0.9	3.9
Straw DF	93.3	90.4	59.8	30.6	12.8	45.8	1.3	3.5	0.9	3.7
Week 6										
Straw HP	93.9	90.5	60.5	30.1	13.2	46.3	0.9	3.4	1.1	2.8
Straw HS1	93.9	91.0	58.9	32.1	12.6	45.3	1.0	3.5	1.0	2.8
Straw DF	93.7	91.1	59.7	31.4	12.4	46.5	0.8	3.6	1.0	2.4
Week 9										
Straw HP	94.1	92.9	64.0	28.9	15.1	47.8	1.1	2.9	0.9	2.4
Straw HS1	94.0	92.9	60.8	32.1	14.0	45.6	1.3	3.5	0.8	2.5
Straw DF	94.1	93.0	61.8	31.2	13.9	46.8	1.1	3.3	0.8	2.7
Week 3										
Diet HP	94.1	34.5	12.1	22.5	3.3	8.2	0.6	31.5	1.3	13.4
Diet HS1	92.2	14.1	4.0	10.1	1.6	2.3	0.1	17.4	1.7	6.3
Diet DF	92.5	34.7	17.7	17.1	3.7	13.0	0.9	18.4	0.4	12.0
Week 6										
Diet HP	94.7	32.5	11.5	21.0	2.3	8.6	0.5	33.0	2.3	13.0
Diet HS1	95.5	16.0	3.0	13.0	0.8	2.1	0.2	18.4	1.6	6.1
Diet DF	95.4	35.6	17.1	18.5	2.8	12.9	1.4	18.4	0.4	12.8
Week 9										
Diet HP	94.3	32.8	11.3	21.5	2.1	8.6	0.5	32.1	1.9	13.3
Diet HS1	94.1	14.2	3.2	11.0	1.0	2.2	0.1	18.5	1.5	6.3
Diet DF	94.5	34.0	17.1	16.9	3.2	12.8	1.2	18.5	0.2	13.2

DM = Dry Matter; NDF = Neutral Detergent Fibre; ADF = Acid Detergent Fibre; H/Cell = Hemicellulose; Lig = Lignin; Cell = Cellulose; R. Ash = Residual Ash; CP = Crude Protein (N x 6.25); EE = Ether Extract.

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RESULTS

A. THE EFFECT OF EXERCISE ON MILK YIELD

CHAPTER FIVE

RESULTS

The full results for each experiment are not presented together, but instead the results for each part of each experiment which were common to all three experiments are discussed together. This method of presentation was chosen because although the three experiments increased in complexity and formed a logical progression of investigation, each experiment made measurements in common (ie. body weight, milk yield, milk composition and blood metabolite levels). Hence it is appropriate to discuss the results from each experiment for each of these factors together.

The dietary treatments increased in complexity in each experiment and the dietary effects on the response to exercise are discussed separately under each heading. The effect of exercise on straw intake was investigated only in Experiment III and the results for this aspect are presented separately.

5.1. MILK YIELD

In this section the results from the experiments which relate to the effect of exercise on daily milk yield are presented. This includes the following aspects:

- the effect of exercise on milk yield over the full walking periods
- the rate of decline of milk yield over the full walking periods (Experiment I only)
- the overall effect of diet on milk yield
- the effect of diet on the response to exercise

- the level of the response to exercise over consecutive days in individual walking weeks
- the level of recovery of milk yield on resting days
- the rate of decline of milk yield over individual walking weeks
- the level of response to exercise over successive walking weeks.

5.1.1. THE EFFECT OF EXERCISE ON MILK YIELD

The amount of walking (8.8 to 10.6 km/d) and climbing (400 to 480m/d) (equivalent to energy demands of 14 to 16.8MJ/d for a 500kg animal) which the animals carried-out in these experiments, reduced mean milk yields by 10.7%, 8.5% and 10.1% in Experiments I, II and III respectively. These differences were calculated by comparing the mean milk yield of walking periods with the mean milk yield for non-walking (control) periods. The mean daily milk yield was shown to be significantly higher for non-walking groups than for walking groups ($p<0.01$ for Experiment I and $p<0.001$ for Experiments II and III; Table 5.1 and Figures 5.1, 5.2 and 5.3).

5.1.2. CALCULATION OF MEAN MILK YIELDS FOR WALKING DAYS ONLY

The reduction in milk yield described above was measured by comparing the mean daily milk yield for every day of the three week walking period (in which animals walked for 15 days and rested for six days) with the results for the three week (Experiment I) or six week (Experiments II and III) non-walking period. The mean daily milk yields for the walking period in each experiment were calculated from the results of both walking and resting days. Since

Table 5.1. Mean milk yields (kg/d) for walking and non-walking groups and for each dietary treatment[1] in Experiments I, II and III

Experiment I

Diet	Non-walking	Walking	SED	p
AA6	5.89	5.26	0.19	<0.01

Experiment II

Diet	Non-walking	Walking	SED	p
AA6	7.15a	6.45c	0.28	<0.05
HS1	8.17b	7.57d	0.28	<0.05
Mean	7.67	7.02	0.19	<0.001
SED	0.23	0.32		

ab, cd = $p<0.001$

Experiment III

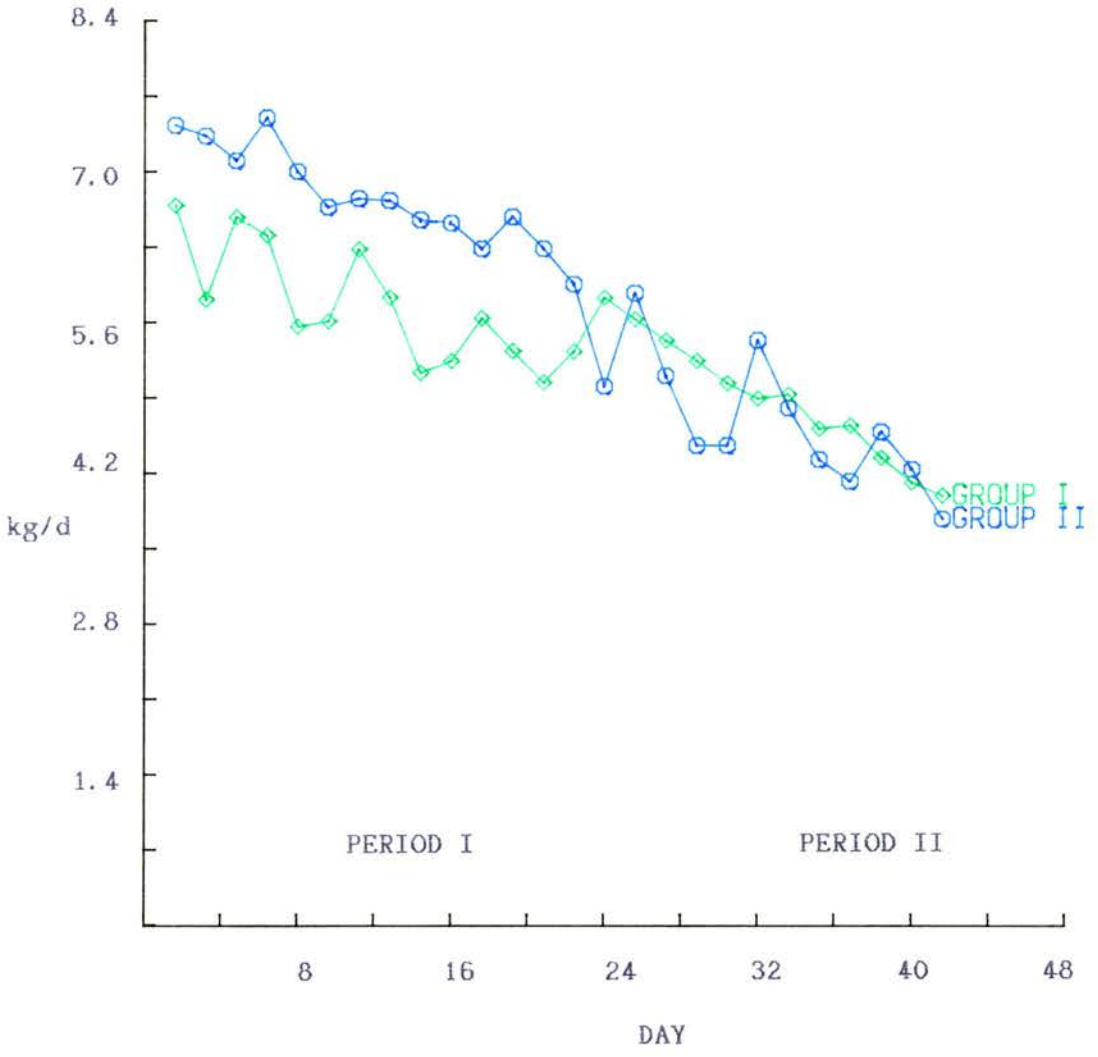
Diet	Non-walking	Walking	SED	p
HS2	4.67a	4.28d	0.15	<0.01
DF	2.88b	2.48e	0.15	<0.01
HP	4.02c	3.65f	0.15	<0.05
Mean	3.86	3.47	0.09	<0.001
SED	0.12	0.17		

All differences in columns = $p<0.001$

Means in columns with the same subscript not sig. diff.

1. AA6 High Roughage Diet
   HS1 High Starch Diet 1 (based on barley)
   HS2 High Starch Diet 2 (based on maize)
   DF Digestible Fibre Diet (based on molassed beet pulp)
   HP High Protein Diet (based on fish meal/soya)

Figure 5.1. Variation in mean milk yield (kg/d) for walking and non-walking groups in each period in Experiment I

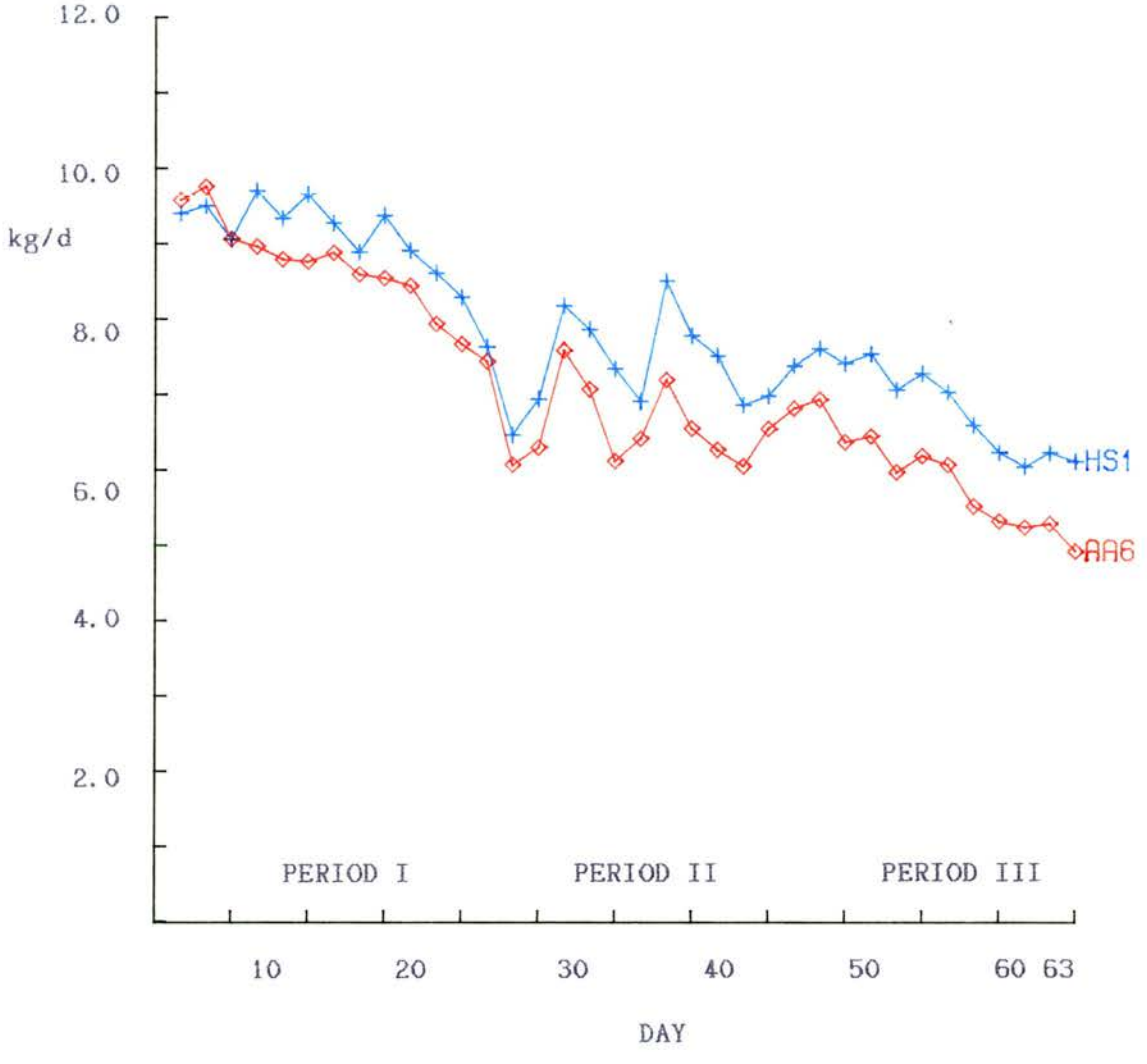


GROUP I: WALKING/NOT WALKING

GROUP II: NOT WALKING/WALKING

All cows fed diet AA6 (30% barley straw)

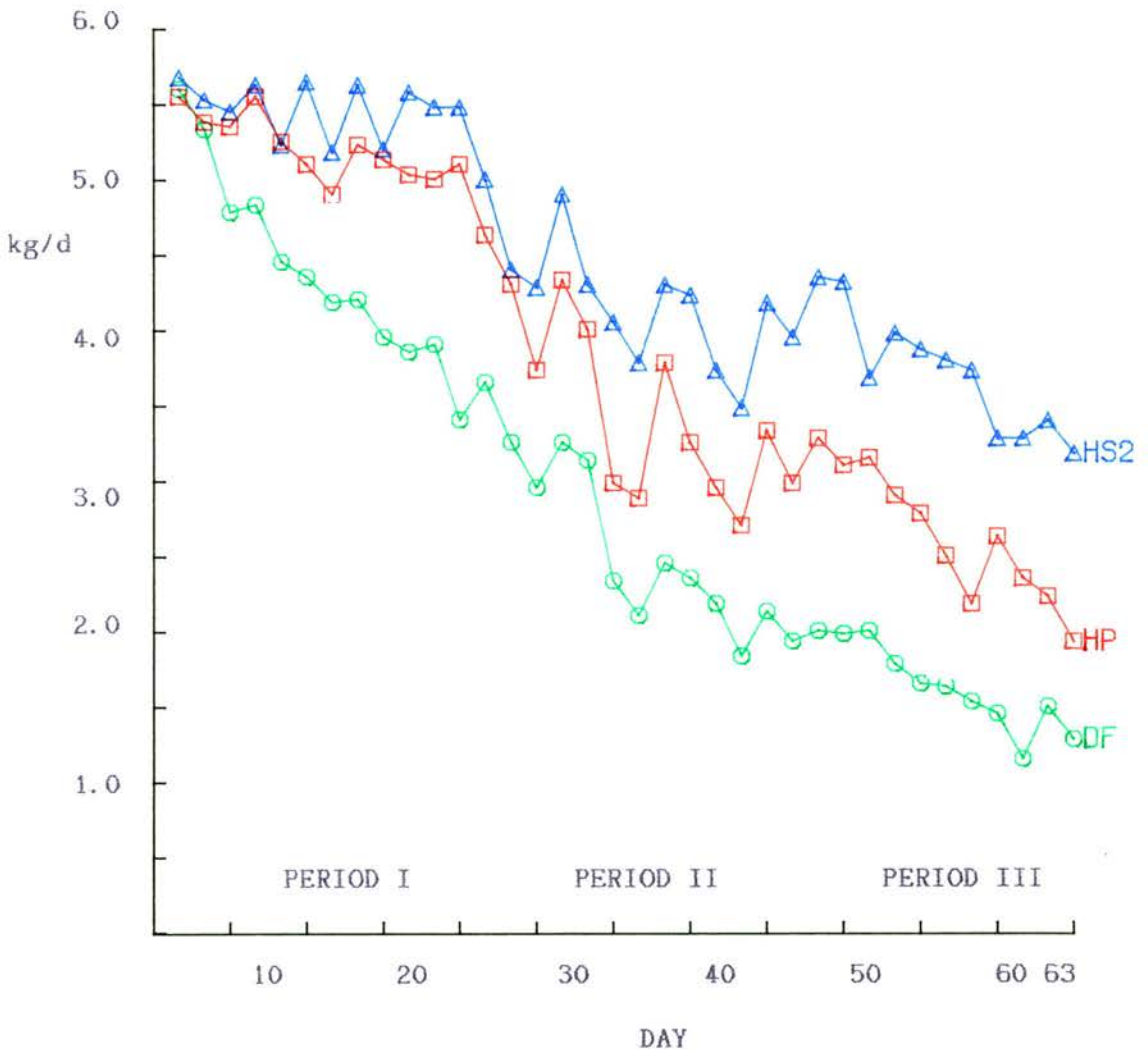
Figure 5.2. Variation in mean milk yield (kg/d) for walking and non-walking groups in each period and for diets AA6 and HS1 in Experiment II



Diet AA6 (30% barley straw; 23% barley)

Diet HS1 (High starch; 46% barley)

Figure 5.3. Variation in mean milk yield (kg/d) for walking and non-walking groups in each period and for diets HS2, DF and HP in Experiment III



Diet HS2 (High starch; 84% maize)

Diet DF (Digestible fibre; 86% molassed beet pulp)

Diet HP (High Protein; 30% fishmeal)

milk yields on resting days increased above the lowest levels on previous walking days, the inclusion of these values in the calculation of the mean milk yield increased the overall mean value for the walking period and reduced the difference between walking and non-walking means.

If the non-walking days (Saturdays and Sundays) are excluded from the calculation of means (for both walking and non-walking periods), the difference between mean milk yields for walking and non-walking periods is greater (ie. 12.4%, 12.2% and 12.3% for Experiments I, II and III respectively, compared with 10.7%, 8.5% and 10.1% when non-walking values are included). Table 5.2. shows the comparison of means calculated by the two methods. These values were calculated from the values used to draw the graphs in Figures 5.1, 5.2 and 5.3.

Although inclusion of the milk yield values on non-walking days tends to reduce the observed mean effect of exercise, it is appropriate to include values for these days when calculating mean values for the walking periods, since this approximates more to the normal situation found in working animals in tropical farming systems.

5.1.3. RATE OF DECLINE FOR WALKING GROUPS COMPARED WITH NON-WALKING GROUPS FOR BOTH PERIODS IN EXPERIMENT I

For Experiment I only (since in this experiment there were both walking and non-walking groups in both periods), regression lines were fitted to compare the rates of change of milk yield in each period. Predicted yields for each cow on the first and last day of

Table 5.2. Mean milk yields (kg/d) calculated with and without non-walking-day values in Experiments I, II and III

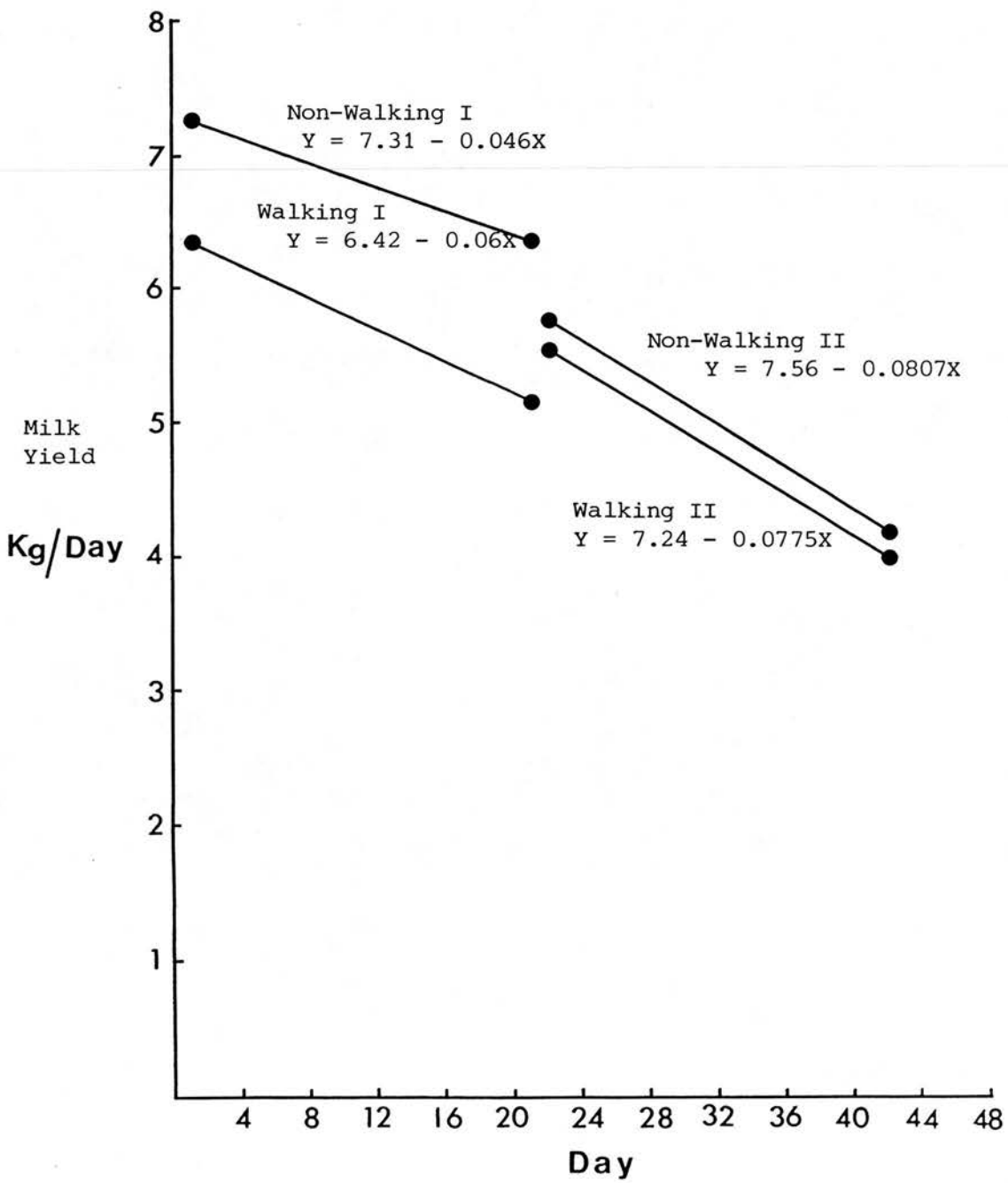
Experiment	I		II				III					
Diet	AA6		AA6		HS1		HS2		DF		HP	
Method of Calculation[1]	1	2	1	2	1	2	1	2	1	2	1	2
Not-walking	5.8	5.9	7.3	7.4	8.0	8.1	4.6	4.6	3.9	4.0	3.0	3.0
Walking	5.2	5.2	6.6	6.5	7.4	7.3	4.2	4.1	3.6	3.5	2.6	2.6
Diff (kg)	0.6	0.7	0.7	0.9	0.6	0.8	0.4	0.5	0.3	0.5	0.4	0.5

1. Method of Calculation: Method 1 = Mean for all values (non-walking and walking days); Method 2 = Mean for walking days only.

each period were calculated. This comparison shows slight differences in the responses between Period I and Period II (Figure 5.4), but these differences were not statistically significant. In Period I the rate of reduction in milk yield with time in the walking group was slightly greater than the rate of reduction in the non-walking group. In period II the rate of reduction in milk yield of the walking group was almost the same as the rate of reduction of the non-walking group.

The same response to exercise might be expected in both periods. The narrower gap between milk yields in the second period suggests a carry-over effect which reduced the yield of the second resting group below the level it would have been had the cows not walked for the previous three weeks. Nevertheless, the slope of

Figure 5.4. Fitted regression lines for milk yield (kg/d) for walking and non-walking groups in each period in Experiment I



the decline in yield did not change significantly with exercise. It might be that at low yields, animal's milk yields become less responsive to exercise.

5.1.4. THE EFFECT OF DIET ON MILK YIELD

Different diets were used in Experiments II and III to investigate the effect of the nature of the diet on the response to exercise (see Sections 4.3.1, 4.4.1 and 4.5.1 for details of diets). Two diets, a high roughage diet (AA6) and a high starch diet (HS1) were offered in Experiment II. The mean milk yield of cows fed diet HS1 (high starch - barley) was significantly higher than the mean milk yield of cows fed diet AA6 ($p<0.001$) (ie. 7.97 kg/d for cows on diet HS1 compared with 6.92 kg/d for cows on diet AA6). At the beginning of the experiment, the treatment groups were balanced (Appendix 2B) for milk yield and the mean milk yield of HS1 cows was in fact slightly lower (0.2kg/d) than that of cows fed diet AA6. Prior to day one of the first experimental period, all cows had been fed a 50/50 mixture of both diets. The mean milk yields for each diet are shown in Table 5.3 and those for walking and non-walking treatments on each diet are shown in Table 5.1.

In Experiment III, three diets were fed - a high starch diet (HS2), a digestible fibre diet (DF) and and a high protein diet (HP). These were designed to provide nutrients in different forms and different quantities. The high starch diet (HS2) produced the highest mean daily milk yield, followed by diet HP and then diet DF (Figure 5.3). These diets were fed as supplements (4kg/d) to *ad libitum* straw. Prior to day one of the first period, cows received

ad libitum straw and 4kg of a mixture (33/33/33) of the three diet supplements. The treatment groups were balanced for milk yield according to the mean of the four days prior to day one of the first period (Appendix 2B). Although the groups had almost identical mean milk yields (5.6kg/d) on day one of the first period, diet had an immediate effect (Figure 5.3) and mean milk yields diverged throughout the first non-walking period. The mean milk yield resulting from diet HS2 (high starch - maize) was 4.54 kg/d, compared with 3.90 kg/d for cows receiving diet supplement HP and 2.75 kg/d for cows receiving diet supplement DF. All dietary differences were shown to be significant by regression analysis of variance ($p<0.001$).

Table 5.3. Mean milk yields (kg/d) for each diet in Experiments I, II and III

Experiment	Diet[1]	Milk Yield(kg/d)
I	AA6	5.58
II	AA6	6.92
	HS1	7.97
	SED	0.19
	p	<0.001
III	HS2	4.54
	DF	2.75
	HP	3.90
	SED	0.10
	p	<0.001

1. AA6 = 30% straw; HS1 = high barley; HS2 = high maize; DF = digestible fibre (sugar beet); HP = high protein

5.1.5. THE EFFECT OF DIET ON THE RESPONSE TO EXERCISE

Diet influenced the response of milk yield to exercise, but the differences resulting from the diet/exercise interaction were not statistically significant. The milk yields resulting from the high starch diets HS1 (barley) and HS2 (maize) declined least when animals walked (0.07/d and 0.08/d respectively). The high protein diet fed in Experiment III resulted in a similar decrease (0.09/d) to the high starch diets, compared with 0.11/d for cows receiving the high roughage (0.30 barley straw) diet AA6 and 0.14/d for cows receiving the digestible fibre (molassed sugar beet pulp) diet DF. The proportional decreases between non-walking and walking groups for each diet in each experiment are summarised in Table 5.4.

Table 5.4. Proportional decreases in milk yield when animals walked for each diet in Experiments I, II and III

Experiment	Diet	Proportional Decrease
I	AA6	0.11
II	AA6	0.10
	HS1	0.07
III	HS2	0.08
	DF	0.14
	HP	0.09

5.1.6. THE RESPONSE TO EXERCISE OVER TIME

The animals usually walked for five consecutive days, on which the milk yield decreased for the first three or four days and

then increased again at weekends when the animals did not walk. The pattern of change during the walking period was the same in each experiment and is shown more clearly in Figures 5.5 and 5.6.

The results presented in sections 5.1.1 to 5.1.5 have been for effects of exercise on milk yield over the full walking periods. Variation occurred in the response however, both over individual walking weeks and over the whole three week walking periods of each experiment. These aspects are considered in the following sections 5.1.6.1 to 5.1.6.5)

5.1.6.1. LEVEL OF THE RESPONSE TO EXERCISE OF MILK YIELD ON CONSECUTIVE WALKING DAYS

Figures 5.5 and 5.6 show the milk yield changes for the walking periods in Experiments I, II and III in greater detail. The non-walking days are indicated with the letters NW. The Y axis values are the values on the day before the first walking day for each group. Each walking week is numbered (1, 2, 3, etc.).

In Experiment I in the first walking group (open symbols) which began walking on a Wednesday, milk yield declined on the first three days (1), then increased on the first two resting days (NW). In the second week (2), the yield declined on the first four walking days, but increased on the last walking day and on the next two resting days. Similarly in the third walking week (3), yield declined on the first three walking days, but increased on the last two walking days. The same pattern was seen in the second walking group (solid symbols). In the second walking week (6) of this group, the yield only declined for two days and then levelled-out.

Figure 5.5. Mean milk yields (kg/d) for walking and non-walking groups in Experiment I showing daily variation and non-walking days

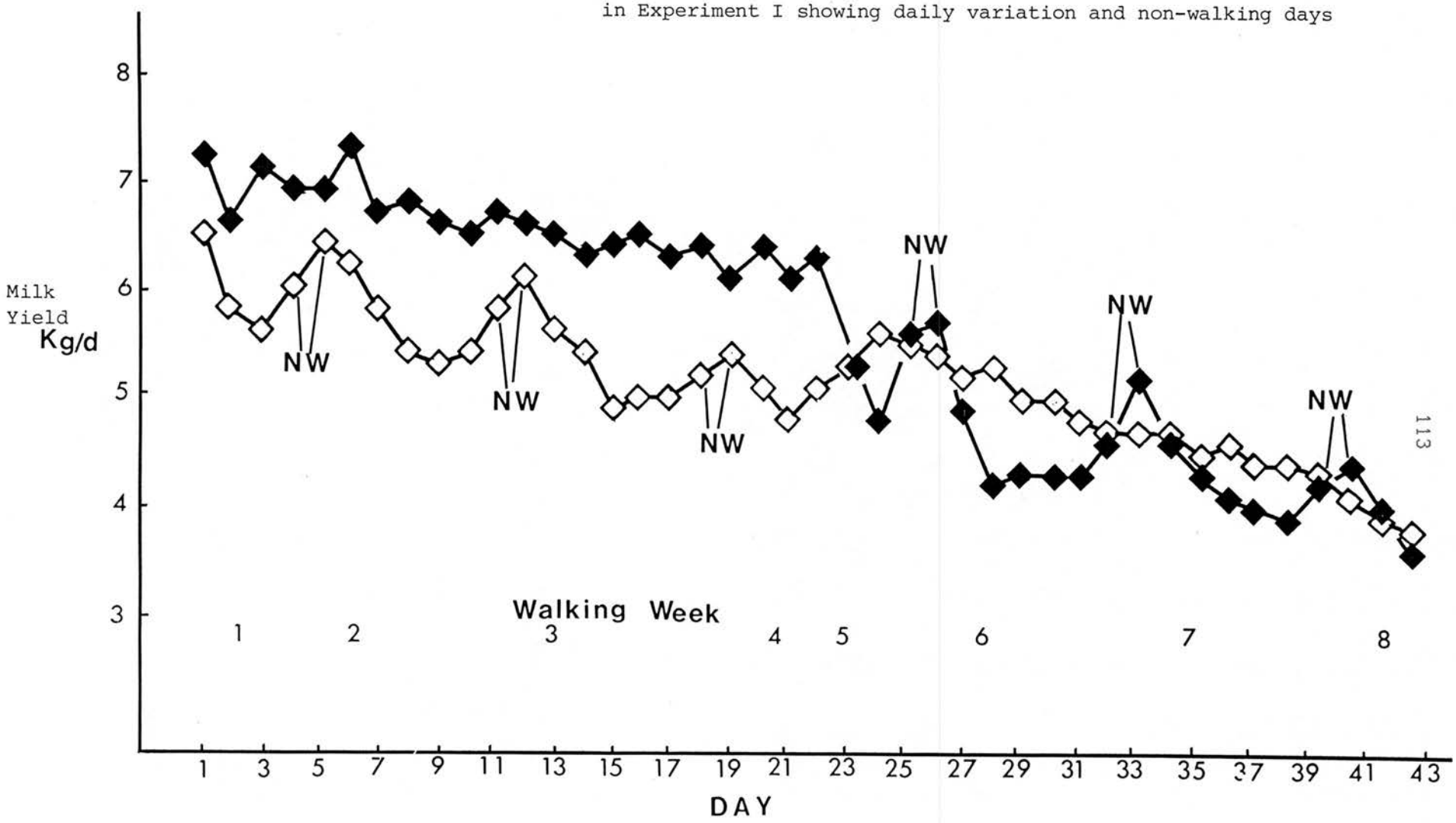
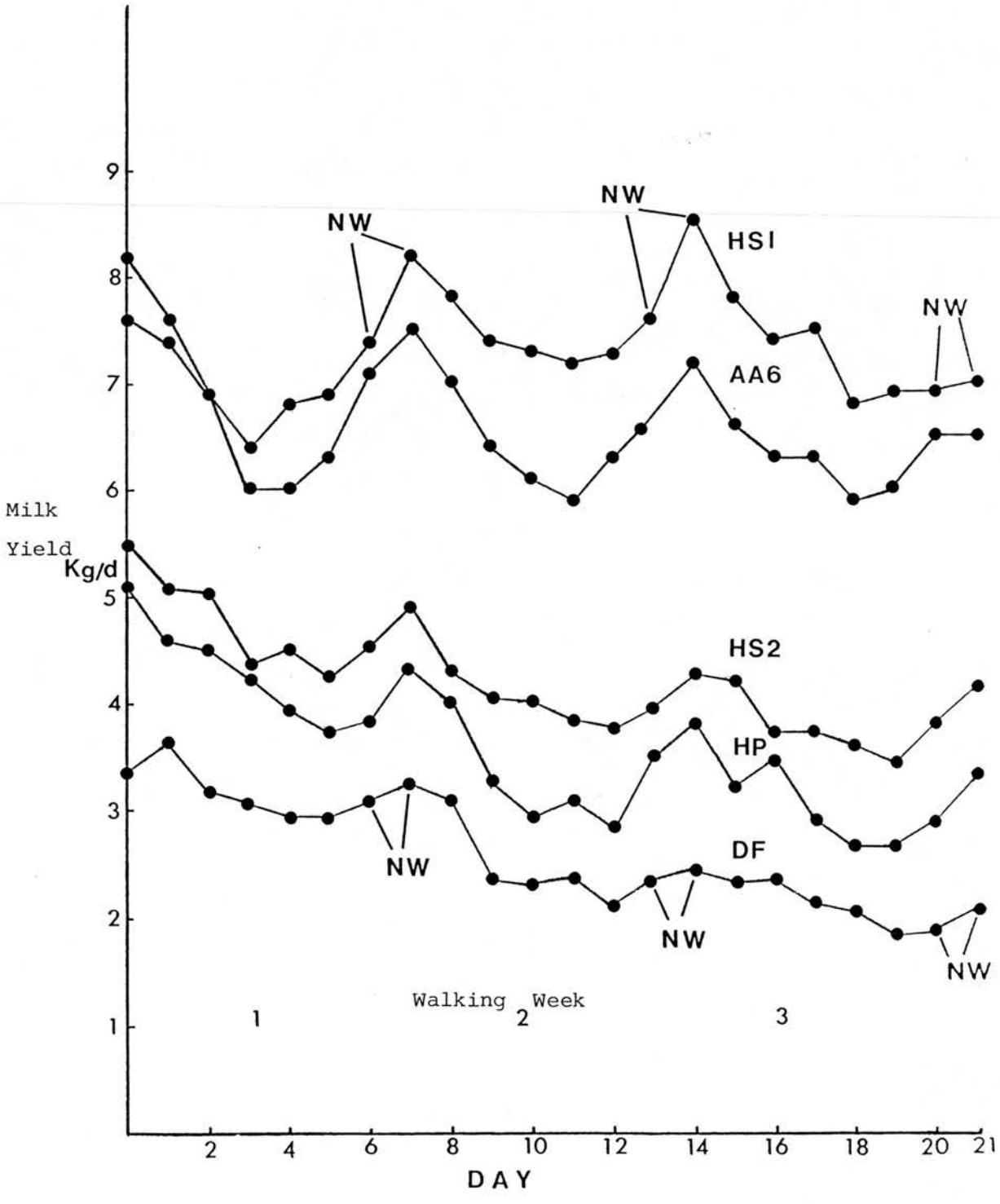


Figure 5.6. Mean milk yields (kg/d) for walking and non-walking groups groups in Experiments II and III showing daily variation and non-walking days



In the third week (7), the decline was steady on all days.

In Experiment II the milk yields declined on the first three days of the first walking week (1), the first four days of the second walking week (2) and on days 1, 2 and 4 of the third walking week (3) for both diets. Rather than declining, milk yields increased on the fifth walking day in each week. Both diets responded in the same way.

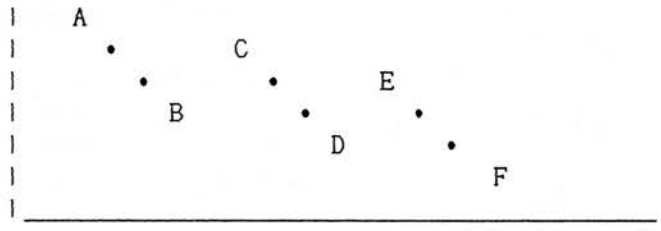
In Experiment III the responses differed according to diet. In the first walking week (1), yields declined on all diets on each of the five walking days except for day four on diet HS2, when the mean yield slightly increased. In week two (2), yields declined on each walking day except for day four on diets HP and DF, when mean yields slightly increased. In week three (3), yields declined each day except day 3 (HS2), day 2 and 4 (HP) and day 3 (DF). The responses in Experiment III were less consistent than in Experiment II. This may be related to the lower overall milk yields in Experiment III.

In all experiments the greatest response in milk yield to walking occurred during the first three walking days with either a reduced response or an increase in milk yield on days four and five of each week. Milk yields always increased on non-walking days.

5.1.6.2. RATE OF DECLINE OF MILK YIELD OVER INDIVIDUAL WALKING WEEKS

In this section, the absolute milk yield values on the day prior to walking and the last walking day of each week are used to calculate the rates of decline over the walking week ie. values

A-B, C-D and E-F in the schematic diagram below. The first value (A) of the whole walking period is the mean of the milk yields of the previous four non-walking days in the first non-walking period:



The proportional differences for each week are greatly influenced by the amount of recovery of milk yield between each walking week (ie. on the non-walking days between values B-C and D-E in the schematic diagram above). If milk yields recover well, the decline in the next week may be exaggerated (see below +).

Over five day walking periods, consumption of high starch diets (HS1 and HS2) resulted in mean rates of decline in milk yield of approximately 0.20, which were similar to the rates of decline for diet AA6 (Table 5.5). The mean weekly proportional declines for diets HS1 and HS2 were 0.18 and 0.21 compared with 0.20 and 0.18 for diets AA6 in Experiments I and II. In Experiment III, the mean weekly declines for diets DF and HP were slightly higher than for other diets and were 0.27 and 0.29 respectively.

In Experiment II, the high starch diet (HS1) showed a similar decline to the high roughage diet (AA6), but would have yielded a lower rate of decline in week three of walking had it not been for the very high value on the day prior to the beginning of the third walking week+. This high value occurred after normal weekend resting and represented a high weekend recovery of yield. The

Table 5.5. Mean milk yields (kg/d) for the day before walking and the last day of walking in each complete five day walking period (Monday to Friday) and the proportional differences between these in Experiments I, II and III

Walking Week		Experiment and Diet					
		I[1]	II			III	
		AA6	AA6	HS1	HS2	DF	HP
1	Value 1[2]	6.22	7.99	8.64	5.48	3.66	5.02
	Value 2[3]	5.03	6.28	6.93	4.28	2.95	3.73
	Proportional Difference	0.19	0.21	0.20	0.22	0.19	0.26
2	Value 1	5.85	7.57	8.17	4.90	3.25	4.33
	Value 2	4.68	6.40	6.90	3.78	2.10	2.88
	Proportional Difference	0.20	0.16	0.16	0.23	0.35	0.34
3	Value 1	-	7.18	8.50	4.30	2.45	3.78
	Value 2	-	6.03	6.87	3.48	1.83	2.70
	Proportional Difference	-	0.16	0.19	0.19	0.25	0.29
	Mean Proportional Decline	0.20	0.18	0.18	0.21	0.27	0.29

1. Only two complete five day periods were available for Experiment I, since animals began walking on a Wednesday and finished on a Tuesday (see Materials and Methods Section 4.2.6).
2. Value 1 in Week 1 is the mean value for the four non-walking days before walking began. For Weeks 2 & 3 it is the value for the previous non-walking day.
3. Value 2 is the value for the last day of the five day period.

patterns of milk yield decline for each five day walking period for each diet in each experiment are shown in Figure 5.7.

Within Experiment III, the high starch (maize) diet (HS2) resulted in the lowest weekly rate of decline and the decline was smaller in week three than in weeks one and two. The rate of decline of milk yield of cows on the other diets (DF and HP) increased in weeks two and three (Table 5.5).

The milk yield associated with diet DF in Experiment III declined least of all in week one, but resulted in a higher decline than any other diet in week two and a reduced rate of decline in week three. The mean rate of decline was 0.27/week.

The milk yield associated with diet HP in Experiment III resulted in a relatively high rate of decline for each week of the walking period and resulted in the greatest mean weekly loss in milk yield (0.29).

5.1.6.3. RECOVERY OF MILK YIELD ON NON-WALKING DAYS

Table 5.6 shows the proportional increase of milk yields on the non-walking days between five-day walking periods (dotted lines in Figure 5.7).

The digestible fibre diet in Experiment III resulted in both a high rate of decline of milk (Table 5.5) and the lowest rate of recovery on resting days of any diet (Table 5.6).

Diet HP, which resulted in the greatest weekly rate of decline when the animals walked, also resulted in the greatest rate of recovery when animals rested (0.23).

Figure 5.7. The pattern of milk yield (kg/d) variation over five day walking periods and two day non-walking periods for each diet in Experiments I, II and III

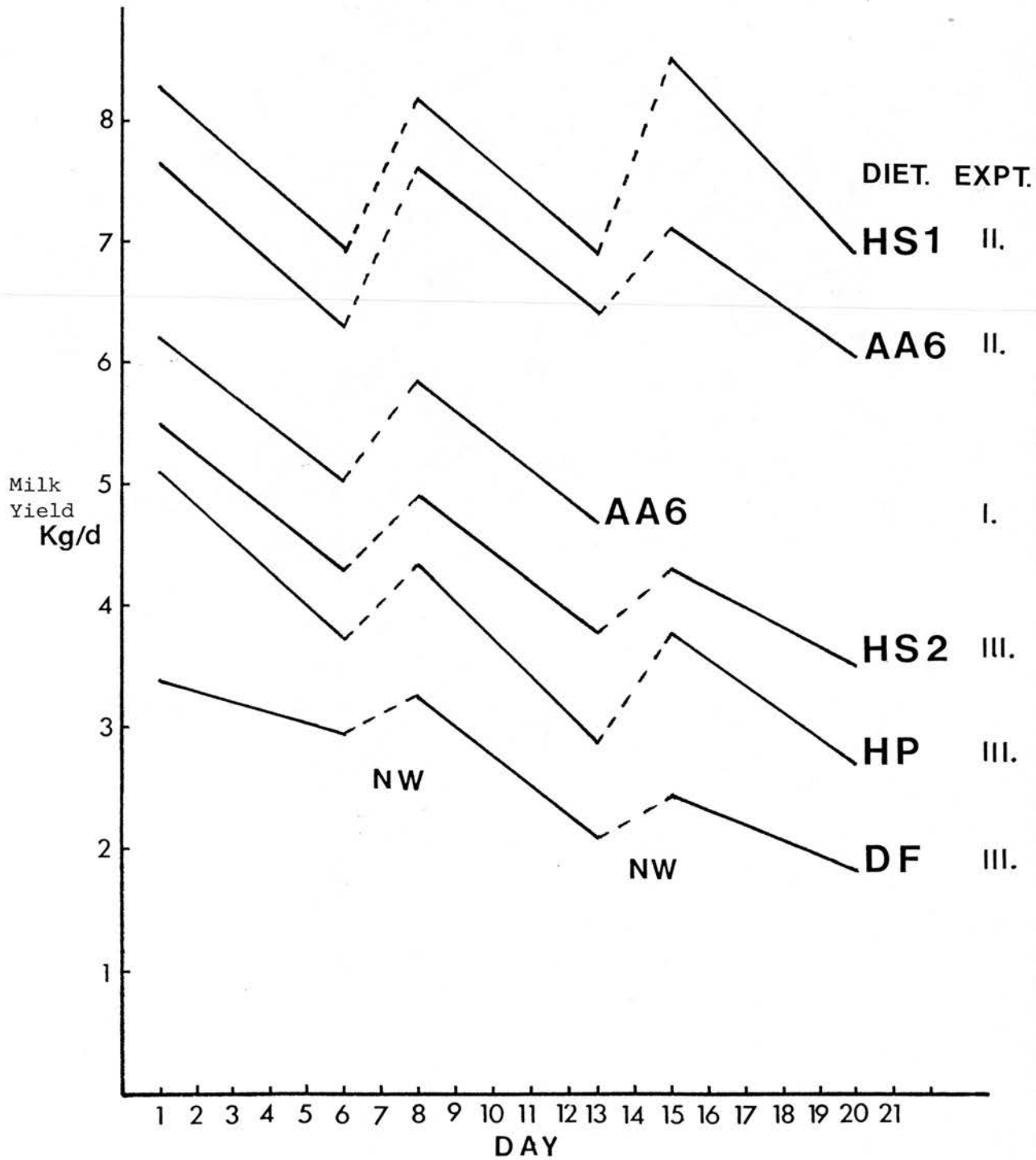


Table 5.6. Mean proportional increases in milk yield during non-walking periods for different diets in each experiment

DIET	Mean Proportional Increase on Non-Walking Days
AA6	0.16
AA6	0.16
HS1	0.21
HS2	0.14
DF	0.13
HP	0.23

5.1.6.4. LEVEL OF RESPONSE TO EXERCISE IN CONSECUTIVE WALKING WEEKS

Section 5.1.6.2. compared weekly rates of milk yield decline for each diet. This section compares mean milk yield values for weeks 1, 2 and 3 of the walking period with mean values for weeks 1, 2 and 3 of the non-walking periods.

The effect of walking on mean weekly milk yield increased in consecutive walking weeks in Experiments I and III, whereas in Experiment II the effect decreased. Mean milk yield values are shown for weeks 1, 2 and 3 in each experiment in Tables 5.7, 5.8 and 5.9. The tables present data calculated a) for walking days only and b) for walking plus resting days. The data used for the calculation of these means are those used for drawing the graphs in Figures 5.1, 5.2 and 5.3.

In Experiment I the relative differences between mean weekly walking and non-walking milk yields for weeks 1, 2 and 3 of the walking period compared with weeks 1, 2 and 3 of the non-walking

periods increased slightly after week one, but subsequently were relatively constant at approximately 0.11 (full data). In Experiment II the relative differences declined from 0.14 to 0.04. This contrasts with Experiment III in which the relative differences increased between week one and week three.

5.1.6.5. RATE OF DECLINE OF MILK YIELD OVER THE FULL WALKING PERIOD

The rate of decline of milk yield over the full walking period (from the day before the first walking day to the last walking day of the walking period) was calculated using the same method as that used in Section 5.1.6.2 for single weeks.

The rate of decline over the full walking period is partly the result of the effect of exercise and partly the result of the natural lactation decline. The percentage differences shown in Table 5.10 of between 0.21 and 0.50 result from a combination of these two factors.

Within experiments, the high starch diets (HS1 and HS2) were associated with the lowest rates of decline. The rates of decline in Experiment III, in which animals were fed higher proportions of roughage (0.50), were higher than in Experiments I and II. The digestible fibre diet was associated with the highest rate of decline in milk yield.

Table 5.7. Mean milk yields (kg/d) for walking and non-walking groups for each walking week calculated by two methods for Experiment I

Method of Calculation	Week[1]	Non-Walking	Walking	Proportional Difference
Walking Values Only	1	6.48	5.86	0.10
	2	6.14	5.26	0.14
	3	5.66	4.90	0.13
	4	5.24	4.59	0.12
Walking & Resting Values	1	6.44	5.98	0.07
	2	6.06	5.41	0.11
	3	5.57	4.95	0.11
	4	5.24	4.59	0.12

1. Weeks 1 and 4 did not have five consecutive walking days

Table 5.8. Mean milk yields (kg/d) for walking and non-walking groups for each walking week calculated by two methods for Experiment II

Method	Week	Diet AA6			Diet HS1		
		Non-Walking	Walking	Prop. Diff.	Walking	Non-Walking	Prop. Diff.
Walking Values Only	1	8.07	6.58	0.19	8.39	7.00	0.17
	2	7.43	6.52	0.12	8.27	7.36	0.11
	3	6.78	6.27	0.08	7.56	7.38	0.02
Walking & Resting Values	1	7.98	6.83	0.14	8.44	7.30	0.14
	2	7.33	6.68	0.09	8.13	7.65	0.06
	3	6.65	6.34	0.05	7.47	7.28	0.03

Table 5.9. Mean milk yields (kg/d) for walking and non-walking groups for each walking week calculated by two methods for Experiment III

Method	Week	Diet HS2			Diet DF			Diet HP		
		NW	W	Prop Diff	NW	W	Prop Diff	NW	W	Prop Diff
Walking Values Only	1	4.88	4.56	0.07	4.27	4.22	0.01	3.60	3.28	0.09
	2	4.62	4.04	0.13	3.91	3.29	0.16	3.01	2.52	0.16
	3	4.37	3.81	0.13	3.73	2.97	0.20	2.64	2.12	0.20
Walking/ Resting Values	1	4.82	4.65	0.04	4.29	4.25	0.01	3.56	3.28	0.08
	2	4.63	4.11	0.11	3.86	3.41	0.12	2.97	2.50	0.16
	3	4.36	3.90	0.11	3.68	3.05	0.17	2.56	2.12	0.17

Table 5.10. Rates of decline of milk yield over the full walking period for each diet in each experiment

Experiment	Diet	Proportional Decline
I	AA6	0.25
II	AA6	0.25
	HS1	0.21
III	HS2	0.36
	DF	0.50
	HP	0.46

5.1.8. SUMMARY OF THE EFFECTS OF EXERCISE AND DIET ON MILK YIELD

- Exercise reduced mean daily milk yields in walking periods compared with non-walking periods by 8.5% to 10.7% depending on experiment (5.1.1.).

- If non-walking days in the walking periods were not included in this calculation, the reduction due to exercise was between 12.2% and 12.4% depending on experiment (5.1.2.).

- In Experiment I there appeared to be a carry-over effect from period one to two which caused a lower than expected milk yield in period two. The milk yield difference was therefore less in period two than in period one (5.1.3.).

- Diet affected milk yields. High starch diets (HS1 and HS2) resulted in higher yields than other diets (5.1.4.).

- Diet had a non-significant effect on the response to exercise. High starch diets resulted in slightly smaller decreases when animals walked (5.1.5.).

- When animals walked, milk yield declined for the first few walking days and then either remained steady or began to increase again (5.1.6.1).

- The overall rates of decline over each walking week varied considerably and no consistent pattern could be discerned (5.1.6.2). The estimation of weekly rate of decline is complicated by the level of recovery on resting days.

- Milk yield recovered by between 14.0 and 23.0% when animals rested for two days between five day walking periods. (5.1.6.3).

- The effect of walking increased with each subsequent walking week in Experiments I and III, but decreased in Experiment II (5.1.6.4).

- Over the whole walking period, total rates of decline (due to exercise and normal lactation decline) varied between 20.5 and 50.0%. High starch diets showed the lowest rates of decline (5.1.6.5).

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RESULTS:

THE EFFECT OF EXERCISE ON MILK COMPOSITION AND CONSTITUENT YIELDS

RESULTS

5.2. MILK COMPOSITION AND CONSTITUENT YIELDS

Milk samples for milk composition analysis were taken from morning and evening milkings each day throughout Experiment I and on Mondays, Wednesdays, Fridays and Sundays in Experiments II and III. The statistical analyses carried out for milk constituents were the same as for milk yields (Sections 4.3.3 and 4.4.4).

5.2.1. MILK FAT

5.2.1.1. THE EFFECT OF EXERCISE ON MILK FAT CONTENT AND YIELD

Exercise significantly ($p<0.001$) increased milk fat contents (g milk fat/kg milk/d) in the milk of animals which were fed each of the diets in Experiments I, II and III. In walking periods, mean fat contents were 43.4, 39.7 and 43.7g/kg milk/d compared with 39.5, 36.2 and 36.7g/kg milk/d in non-walking groups in Experiments I, II and III respectively (Table 5.11). Milk fat content varied inversely with milk yield and as milk yield decreased, milk fat content increased (Figures 5.8, 5.9 and 5.10).

Exercise significantly ($p<0.01$) increased the milk fat yield (g/d) of animals fed diet HP in Experiment III, but had no statistically significant effect on fat yields in the milk of animals fed any of the diets in Experiments I and II and diets HS2 and DF in Experiment III. The mean milk fat yields for walking groups in Experiments I, II and III respectively were 228, 273 and 151g/d compared with 233, 270 and 143g/d for the non-walking groups (Table 5.12).

Table 5.11. Mean milk fat contents (g/kg) for walking and non-walking groups and for each dietary treatment[1] in Experiments I, II and III

Experiment I

Diet	Non-walking	Walking	SED	p
AA6	39.5	43.4	0.6	<0.001

Experiment II

Diet	Non-walking	Walking	SED	p
AA6	39.6a	45.4c	1.2	<0.001
HS1	32.8b	34.0d	1.2	<0.001
Mean	36.2	39.7	0.9	<0.001
SED	1.0	1.4		

ab, cd = $p<0.001$

Experiment III

Diet	Non-walking	Walking	SED	p
HS2	35.3a	40.0c	1.2	<0.001
DF	35.1a	42.4c	1.1	<0.001
HP	39.7b	48.8d	1.1	<0.001
Mean	36.7	43.7	0.6	<0.001
SED	0.9	1.3		

All differences in columns = $p<0.001$

Means in columns with the same subscript not sig. diff

1. AA6 High Roughage Diet
   HS1 High Starch Diet 1 (based on barley)
   HS2 High Starch Diet 2 (based on maize)
   DF Digestible Fibre Diet (based on molassed beet pulp)
   HP High Protein Diet (based on fish meal/soya)

Table 5.12. Mean milk fat yields (g/d) for walking and non-walking groups and for each dietary treatment[1] in Experiments I, II and III

Experiment I

Diet	Non-walking	Walking	SED	p
AA6	232.5	228.3	8.25	ns

Experiment II

Diet	Non-walking	Walking	SED	p
AA6	290.8a	299.0a	14.5	ns
HS1	249.7b	245.8b, c	14.5	ns
Mean	270.3	272.7	10.2	ns
SED	11.8	16.7		

ab = $p<0.001$; ac = $p<0.01$

Experiment III

Diet	Non-walking	Walking	SED	p
HS2	155.3a	160.8a	6.2	ns
DF	109.9b	111.1b	6.2	ns
HP	163.6a	180.7c	6.2	<0.01
Mean	142.9	150.8	3.5	<0.05
SED	5.1	7.1		

ab, bc = $p<0.001$; ac = $p<0.01$

Means in columns with the same subscript not sig. diff

1. AA6 High Roughage Diet
   HS1 High Starch Diet 1 (based on barley)
   HS2 High Starch Diet 2 (based on maize)
   DF Digestible Fibre Diet (based on molassed beet pulp)
   HP High Protein Diet (based on fish meal/soya)

Figure 5.8. Variation in milk fat yields (g/d) and milk fat contents (g/kg milk/d) for animals in each group in Experiment I

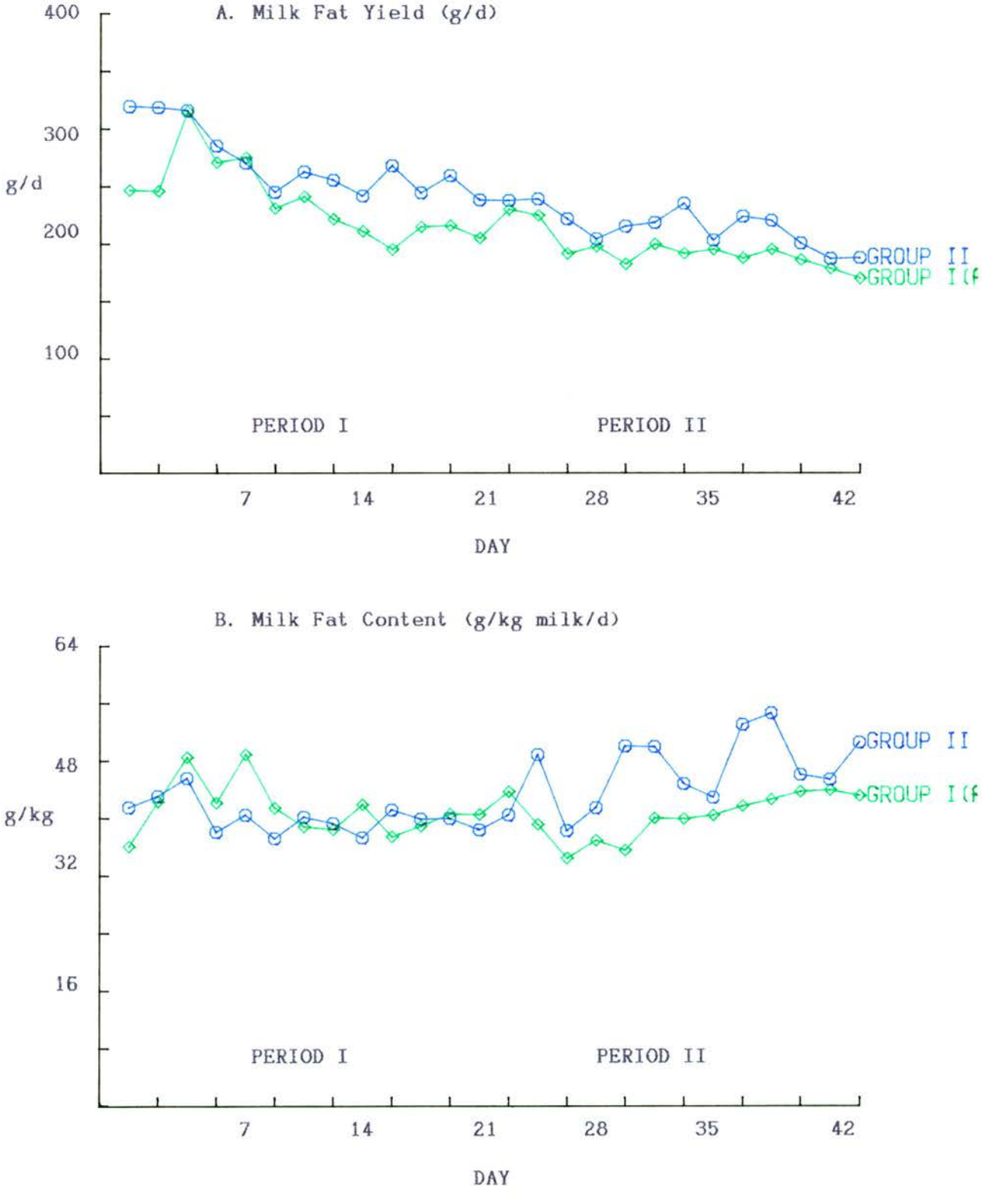


Figure 5.9. Variation in milk fat yields (g/d) and milk fat contents (g/kg milk/d) for animals in each group in Experiment II

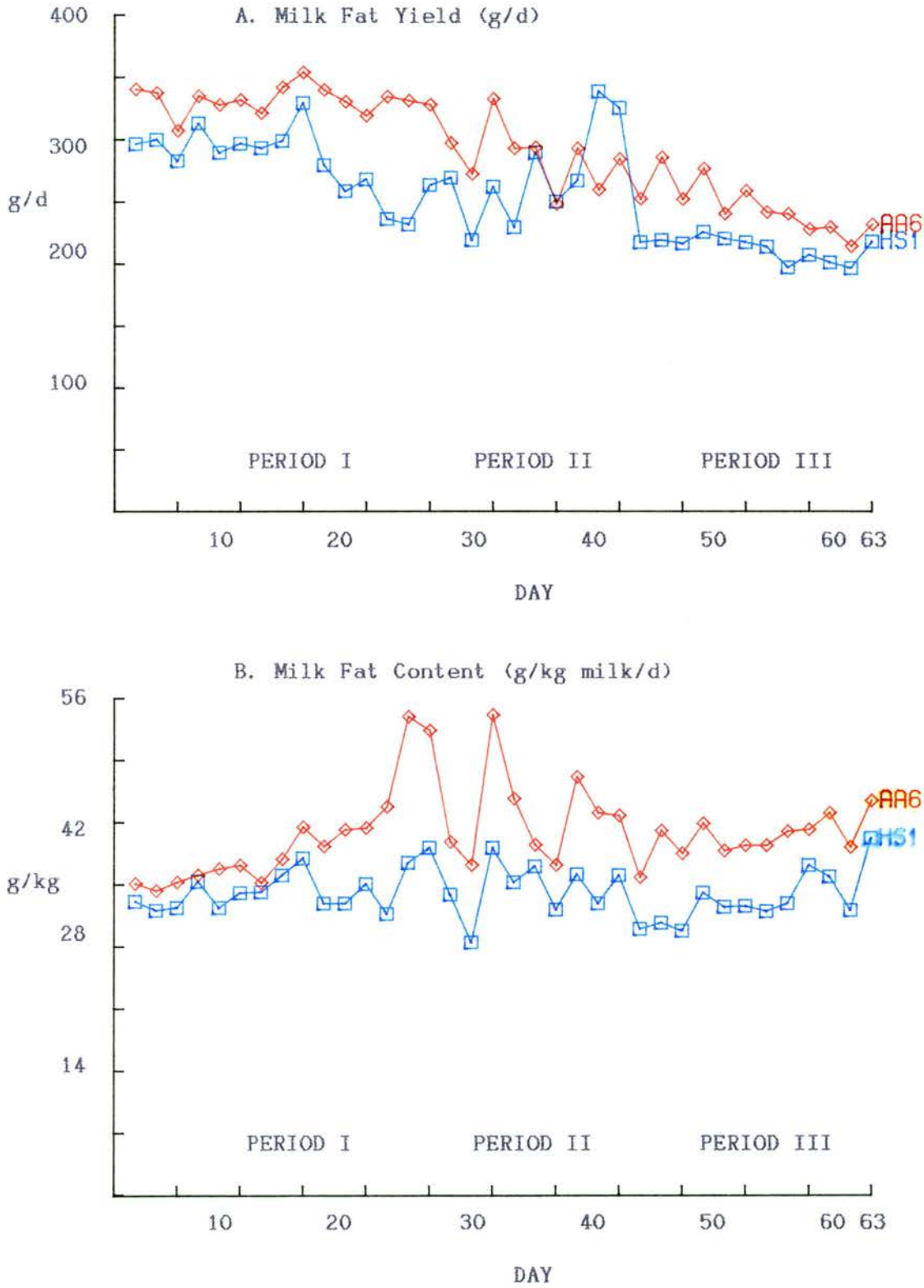
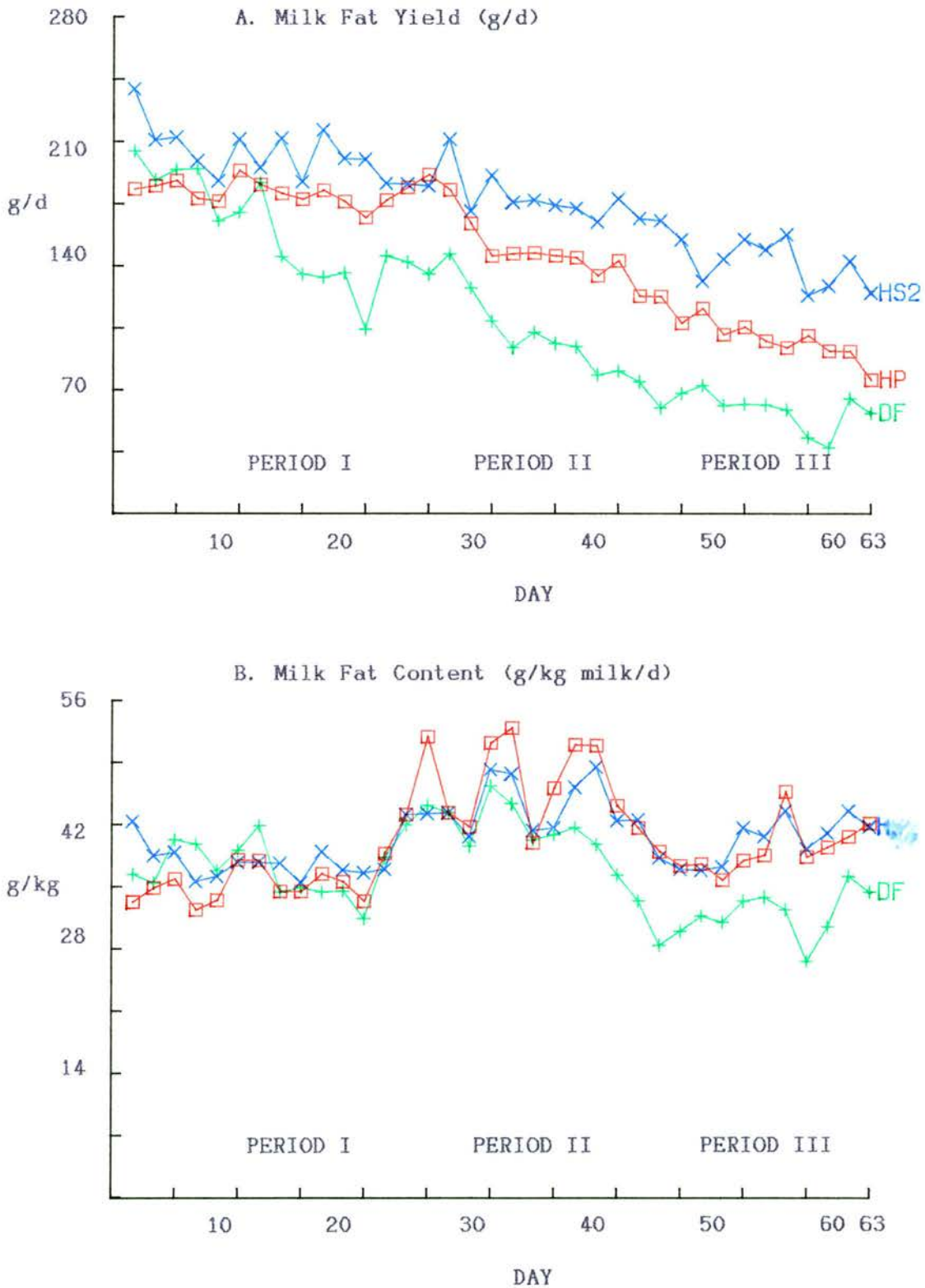


Figure 5.10. Variation in milk fat yields (g/d) and milk fat contents (g/kg milk/d) for animals in each group in Experiment III



For Experiment I, which had a cross-over design, regression lines were fitted for milk fat yield in walking and non-walking groups in each period (Figure 5.11). The regression lines show a more rapid decline for walking groups in both periods, though in period II walking group yields were greater than control yields. There were no statistically significant differences between the overall rates of decline for milkfat yield.

5.2.1.2. THE EFFECT OF DIET ON MILK FAT CONTENT AND YIELD

Diet had a significant ($p<0.001$) effect on milk fat content (g/kg milk/d) in Experiments II and III (Table 5.13).

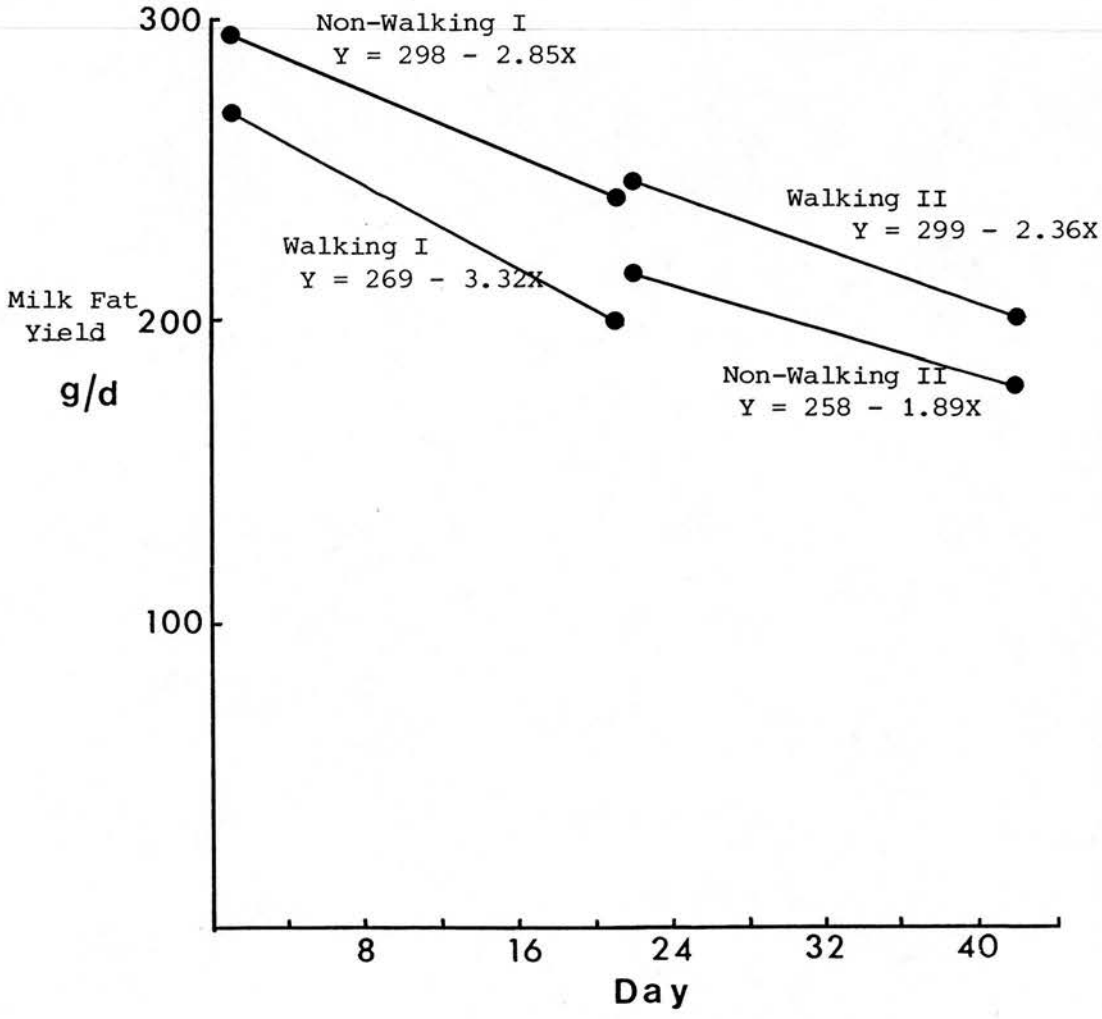
Table 5.13. Mean milk fat contents (g/kg) and yields (g/d) for each diet in Experiments I, II and III

Experiment	Diet	Content(g/kg)	Yield(g/d)
I	AA6	41.5	230.4
II	AA6	41.5	293.5
	HS1	33.2	248.4
	SED	0.8	9.6
	p	<0.001	<0.001
III	HS2	36.9[a]	157.1[a]
	DF	37.5[a]	110.3[b]
	HP	42.8[b]	169.3[c]
	SED	0.8	4.1
	p	<0.001	<0.01[a-c] <0.001[ab, bc]

In columns, values with the same superscript are not significantly different (see Section 4.2.8)

In Experiment II the milk of animals fed the high roughage diet

Figure 5.11. Fitted regression lines for milk fat yield (g/d) for walking and non-walking groups in each period in Experiment I



(AA6) had a significantly higher fat content than the milk of animals fed the high starch diet (HS1). As a result, even though the high starch diet resulted in higher milk yields than the high roughage diet (Figure 5.2, section 5.1.1), the fat yields (g/d) of the high starch diet were significantly ($p<0.001$) lower.

In Experiment III, the high starch diet (HS2) and the digestible fibre diet (DF) resulted in significantly lower ($p<0.001$) fat contents (g/kg milk/d) than the high protein diet (HP). Diets HP and HS2 resulted in significantly higher milk fat yields (g/d) than diet DF ($p<0.01$).

5.2.1.3. THE EFFECT OF DIET ON THE RESPONSE TO EXERCISE

There was a significant ($p<0.05$) interaction between diet and exercise which affected milk fat content (g/kg milk/d) in Experiment II and III, but there was no significant interaction effect on milk fat yield (g/d) in either experiment. Thus, although when animals walked the fat content of their milk increased in all cows on all diets, the increase was greater for AA6 cows ($p<0.05$) in Experiment I and DF and HP cows ($p<0.05$) in Experiment III.

The proportional changes in milk fat content and yield between non-walking and walking groups for each diet are shown in Table 5.14.

Table 5.14. Proportional changes in milk fat content (g/kg milk/d) and yield (g/d) when animals walked given for each diet in Experiments I, II and III

Experiment	Diet	Proportional Change	
		Content (g/kg milk/d)	Yield (g/d)
I	AA6	+0.10	-0.02
II	AA6	+0.15a	+0.03a
	HS1	+0.04b	-0.02a
III	HS2	+0.13a	+0.04a
	DF	+0.21b	+0.01a
	HP	+0.23b	+0.06a

Within experiments ab = $p<0.05$

5.2.2. MILK PROTEIN

5.2.2.1. THE EFFECT OF EXERCISE ON MILK PROTEIN CONTENT AND YIELD

Protein contents (g/kg milk/d) of milk were not affected by exercise in cows on any diet in any experiment. As daily milk yields decreased due to exercise, daily production of milk protein decreased in proportion. The mean milk protein contents of milk for non-walking and walking groups were 29.1, 37.8 and 35.6g/kg milk and 29.8, 37.4 and 35.3g/kg milk respectively for each experiment (Table 5.15; Figures 5.12, 5.13 and 5.14). These changes were similar to the changes observed in milk yield (Section 5.1.1).

Since the protein content of milk was unchanged when animals exercised, but milk yield declined, exercise had a negative effect on protein yields (g/d). The mean yields (g/d) for milk protein for non-walking and walking groups in each experiment were 171, 277 and 128g/d

Table 5.15. Mean milk protein content (g/kg) for walking and non-walking groups and for each dietary treatment[1] in Experiments I, II and III

Experiment I

Diet	Non-walking	Walking	SED	p
AA6	29.1	29.7	0.6	ns

Experiment II

Diet	Non-walking	Walking	SED	p
AA6	36.8a	36.7a	0.6	ns
HS1	38.8b	38.0a, b	0.6	ns
Mean	37.8	37.4	0.4	ns
SED	0.5	0.7		

ab = $p<0.001$

Experiment III

Diet	Non-walking	Walking	SED	p
HS2	30.4a	30.4a	1.0	ns
DF	35.0b	34.4b	1.0	ns
HP	41.5c	41.1c	1.0	ns
Mean	35.6	35.3	0.6	ns
SED	0.8	1.2		

ab, ac, bc = $p<0.001$

Means in columns with the same subscript not sig. diff

1. AA6 High Roughage Diet
   HS1 High Starch Diet 1 (based on barley)
   HS2 High Starch Diet 2 (based on maize)
   DF Digestible Fibre Diet (based on molassed beet pulp)
   HP High Protein Diet (based on fish meal/soya)

Figure 5.12. Variation in milk protein yields (g/d) and milk protein contents (g/kg milk/d) for animals in each group in Experiment I

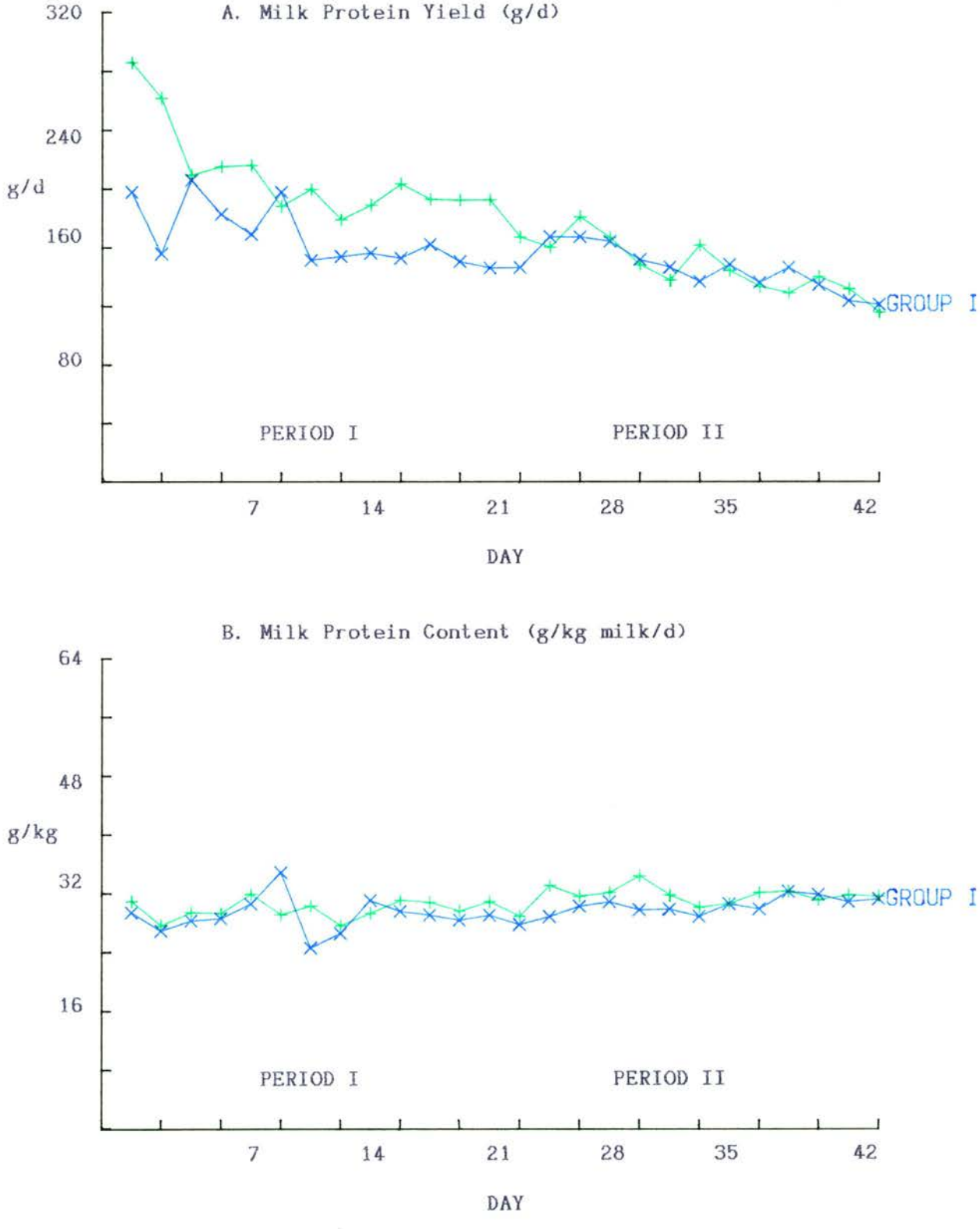


Figure 5.13. Variation in milk protein yields (g/d) and milk protein contents (g/kg milk/d) for animals in each group in Experiment II

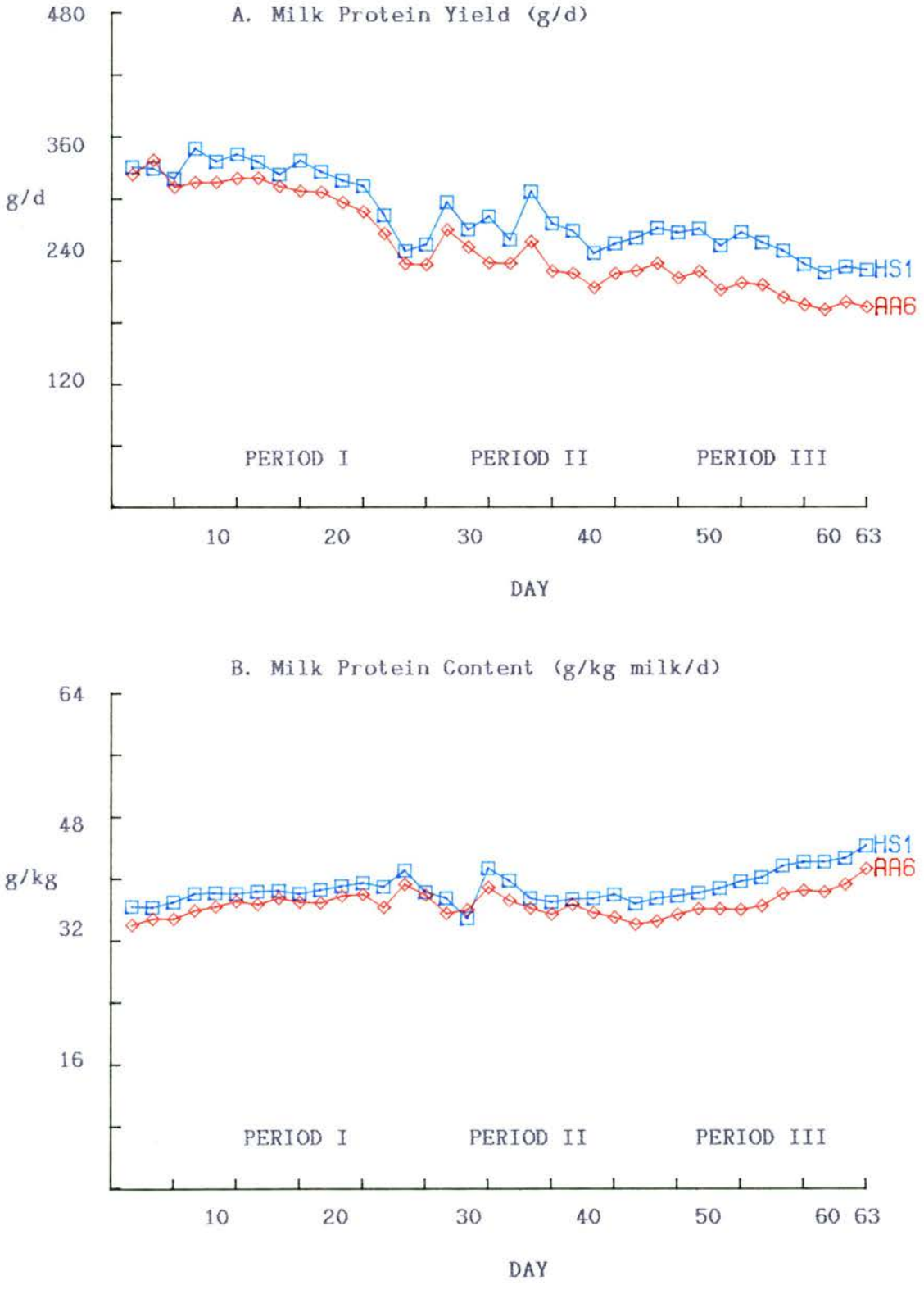
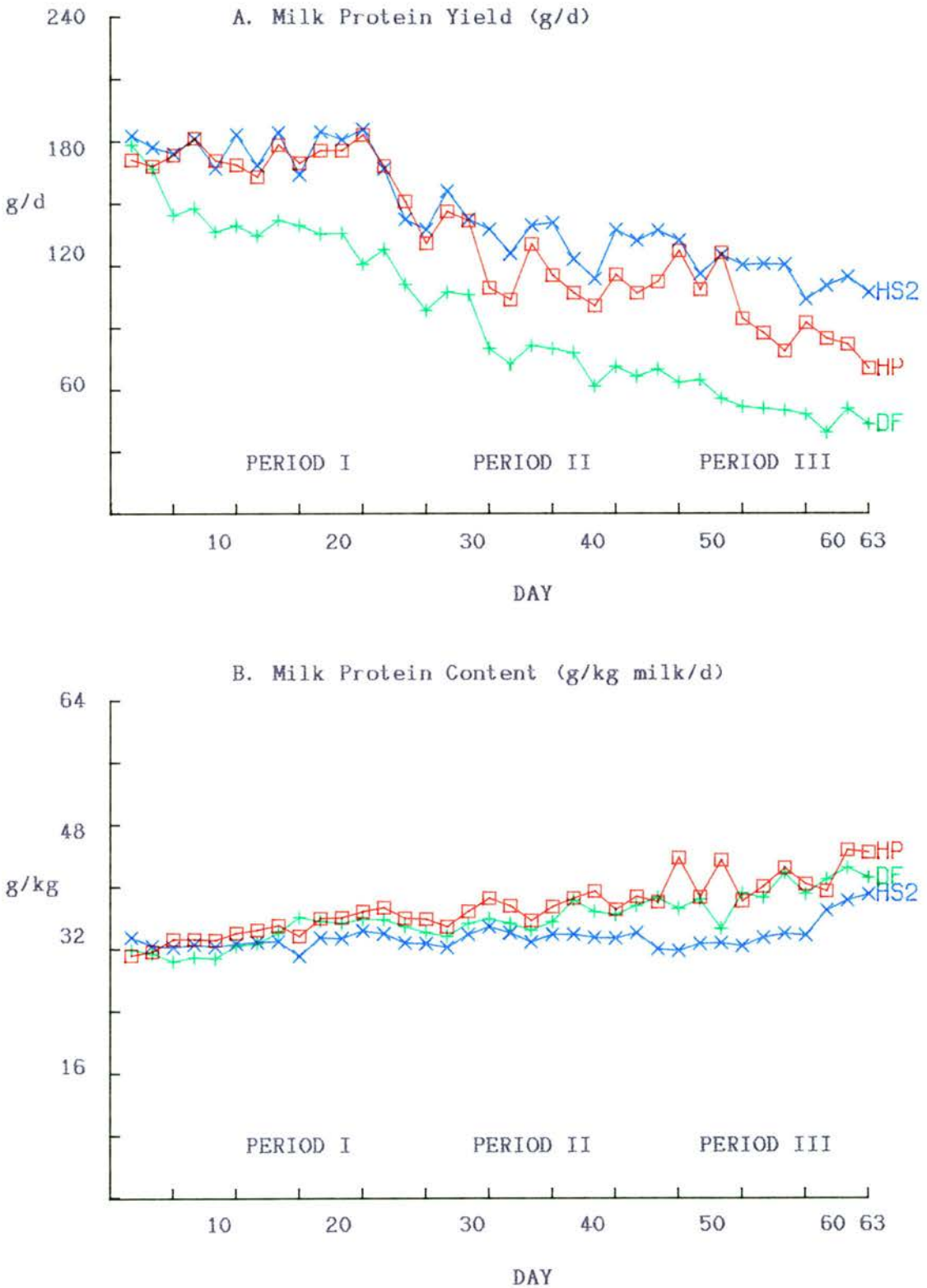


Figure 5.14. Variation in milk protein yields (g/d) and milk protein contents (g/kg milk/d) for animals in each group in Experiment III



and 156, 256 and 118g/d respectively. The mean values for walking groups were 0.09, 0.08 and 0.08 lower than mean non-walking group values and the differences were statistically significant ($p<0.01$ for Experiments I and II and $p<0.001$ for Experiment III; Table 5.16).

For milk protein yields the slopes of fitted regression lines of the walking groups in Experiment I were greater than for non-walking groups in both periods (Figure 5.15), but the rates of decline between groups were not significantly different.

5.2.2.2. THE EFFECT OF DIET ON MILK PROTEIN CONTENT AND YIELD

Diet had a significant effect on milk protein content (g/kg milk/d) and yields (g/d) in Experiments II and III ($p<0.001$; Table 5.17). In Experiment II the high starch diet (HS2) produced higher milk protein contents and higher milk protein yields than the high roughage diet (AA6). In Experiment III the high starch and high protein diets produced similar milk protein contents and yields which were both significantly higher ($p<0.001$) than the milk protein contents and yields produced by the digestible fibre diet (Table 5.17).

5.2.2.3. THE EFFECT OF DIET ON THE RESPONSE TO EXERCISE

The protein contents of milk were almost unchanged in the walking period compared with the non-walking period, but milk protein yields decreased slightly on all diets as a result of walking. The proportional decrease between non-walking and walking groups for each diet are shown in Table 5.18.

These changes were similar to the changes in milk yield and were not significantly different. There was no diet/exercise interaction

Table 5.16. Mean milk protein yields (g/d) for walking and non-walking groups and for each dietary treatment[1] in Experiments I, II and III

Experiment I

Diet	Non-walking	Walking	SED	p
AA6	171.4	156.0	4.7	<0.01

Experiment II

Diet	Non-walking	Walking	SED	p
AA6	255.4a	233.7b	9.6	<0.05
HS1	297.4c	277.6d	9.6	<0.05
Mean	276.6	255.7	6.7	<0.01
SED	7.9	11.1		

ac, bd = p<0.001

Experiment III

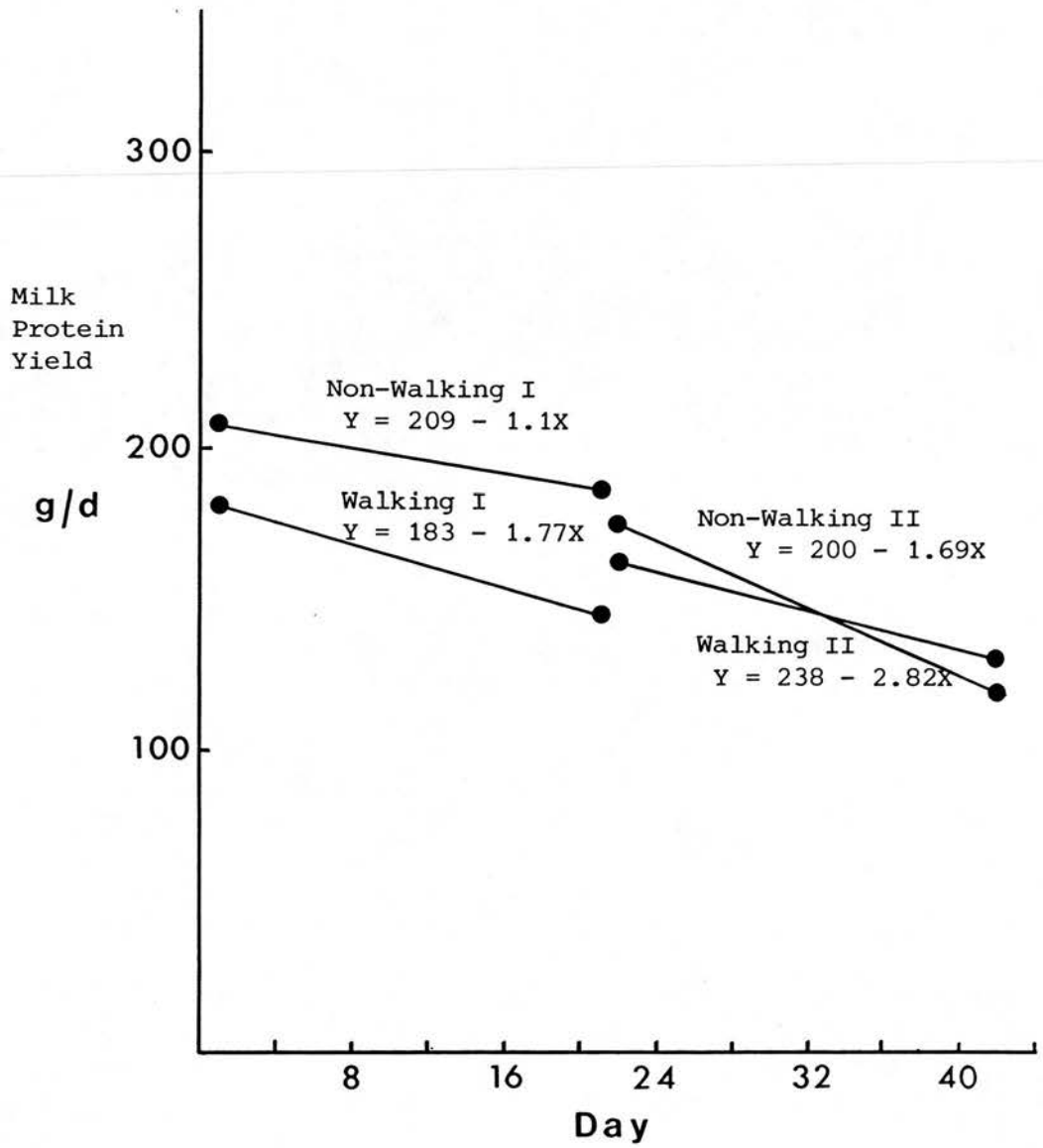
Diet	Non-walking	Walking	SED	p
HS2	143.4a	133.0c	4.9	<0.05
DF	91.5b	82.1b	4.9	ns
HP	148.2a	139.4a, c	4.9	ns
Mean	127.7	118.2	2.8	<0.001
SED	4.0	5.7		

ab, bc = p<0.001

Means in columns with the same subscript not sig. diff

1. AA6 High Roughage Diet
   HS1 High Starch Diet 1 (based on barley)
   HS2 High Starch Diet 2 (based on maize)
   DF Digestible Fibre Diet (based on molassed beet pulp)
   HP High Protein Diet (based on fish meal/soya)

Figure 5.15. Fitted regression lines for milk protein yield (g/d) for walking and non-walking groups in each period in Experiment I



which affected protein content or yield in any experiment.

Table 5.17. Mean protein contents (g/kg) and yields (g/d) for each diet in Experiments I, II and III

Experiment	Diet	Content(g/kg)	Yield(g/d))
I	AA6	29.4	163.7
II	AA6	36.8	248.2
	HS1	38.5	290.8
	SED	0.4	6.4
	p	<0.001	<0.001
III	HS2	30.4	139.9[a]
	DF	34.8	88.3[b]
	HP	41.4	145.3[a]
	SED	0.7	3.3
	p	<0.001	<0.001[ab]

Table 5.18. Proportional changes in protein content (g/kg milk/d) and yield (g/d) when animals walked for each diet in Experiments I, II and III

Experiment	Diet	Proportional Change	
		Content (g/kg milk/d)	Yield (g/d)
I	AA6	+0.02	-0.09
II	AA6	0.00	-0.09
	HS1	-0.02	-0.07
III	HS2	0.00	-0.07
	DF	-0.02	-0.10
	HP	-0.01	-0.06

5.2.3. LACTOSE[1]

5.2.3.1. THE EFFECT OF EXERCISE ON LACTOSE CONTENT AND YIELD

The mean daily lactose contents (g/kg milk/d) for each experiment were 58.9, 46.8 and 44.0 g/kg milk respectively for non-walking groups and 58.5, 44.6 and 43.1g/kg milk respectively for walking groups. The differences between these lactose contents were not statistically significant in Experiments I and II, but in Experiment III exercise resulted in a significantly lower ($p<0.05$) lactose content (Table 5.19).

Exercise had a significant effect on mean lactose yields (g/d) in all experiments (Figures 5.16, 5.17 and 5.18; $p<0.01$ for Experiment I and $P<0.001$ for Experiments II and III; Tables 5.20). The mean yields (g/d) of lactose for non-walking and walking groups in each experiment were 347.5, 364.1 and 178.8g/d and 307.6, 330.3 and 154.5g/d respectively, which represented 0.11, 0.09 and 0.14 differences for each experiment. The change in lactose production due to walking was similar to, but more pronounced than, that for milk protein.

Regression lines for each period in Experiment I (Figure 5.19) show a greater decline in lactose yield with time in walking animals in period I, but a smaller decline over time in period II. No significant difference was demonstrated between the percentage differences in decline between walking and non-walking groups in either period.

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1. The analyses of milk carried out for lactose differed between Experiment I and Experiments II and III. The analysis for Experiment I was not a specific analysis, but determined lactose by difference from solids not fat and minerals/protein (N x 6.25). The analyses for Experiments II and III were more specific and estimated lactose directly by infra-red spectrophotometry (see Section 4.2.7.2).

Table 5.19. Mean lactose contents (g/kg) for walking and non-walking groups and for each dietary treatment[1] in Experiments I, II and III

Experiment I

Diet	Non-walking	Walking	SED	p
AA6	58.9	58.5	0.4	ns

Experiment II

Diet	Non-walking	Walking	SED	p
AA6	47.1a	46.6a	0.5	ns
HS1	46.4a	46.1a	0.5	ns
Mean	46.8	46.4	0.3	ns
SED	0.4	0.5		

Experiment III

Diet	Non-walking	Walking	SED	p
HS2	45.3a	45.1a	0.7	ns
DF	41.5b	39.5c	0.7	<0.01
HP	45.2a	44.7a	0.7	ns
Mean	44.0	43.1	0.4	<0.05
SED	0.6	0.8		

ab, ac = $p<0.001$

Means in columns with the same subscript not sig. diff

1. AA6 High Roughage Diet
   HS1 High Starch Diet 1 (based on barley)
   HS2 High Starch Diet 2 (based on maize)
   DF Digestible Fibre Diet (based on molassed beet pulp)
   HP High Protein Diet (based on fish meal/soya)

Table 5.20. Mean lactose yields (g/d) for walking and non-walking groups and for each dietary treatment[1] in Experiments I, II and III

Experiment I

Diet	Non-walking	Walking	SED	p
AA6	347.5	307.6	12.5	<0.01

Experiment II

Diet	Non-walking	Walking	SED	p
AA6	342.3a	306.9b	13.7	<0.01
HS1	385.8c	353.8d	13.7	<0.05
Mean	364.1	330.3	9.7	<0.001
SED	11.2	15.8		

ac = p<0.001; bd = p<0.01

Experiment III

Diet	Non-walking	Walking	SED	p
HS2	214.8a	192.4d	7.2	<0.01
DF	132.6b	104.0e	7.2	<0.001
HP	189.1c	166.9f	7.2	<0.01
Mean	178.8	154.5	4.2	<0.001
SED	5.9	8.3		

ab, ac, bc, de, ef = p<0.001; df = 0.01

Means in columns with the same subscript not sig. diff

1. AA6 High Roughage Diet
   HS1 High Starch Diet 1 (based on barley)
   HS2 High Starch Diet 2 (based on maize)
   DF Digestible Fibre Diet (based on molassed beet pulp)
   HP High Protein Diet (based on fish meal/soya)

Figure 5.16. Variation in lactose yields (g/d) and lactose contents (g/kg milk/d) for animals in each group in Experiment I

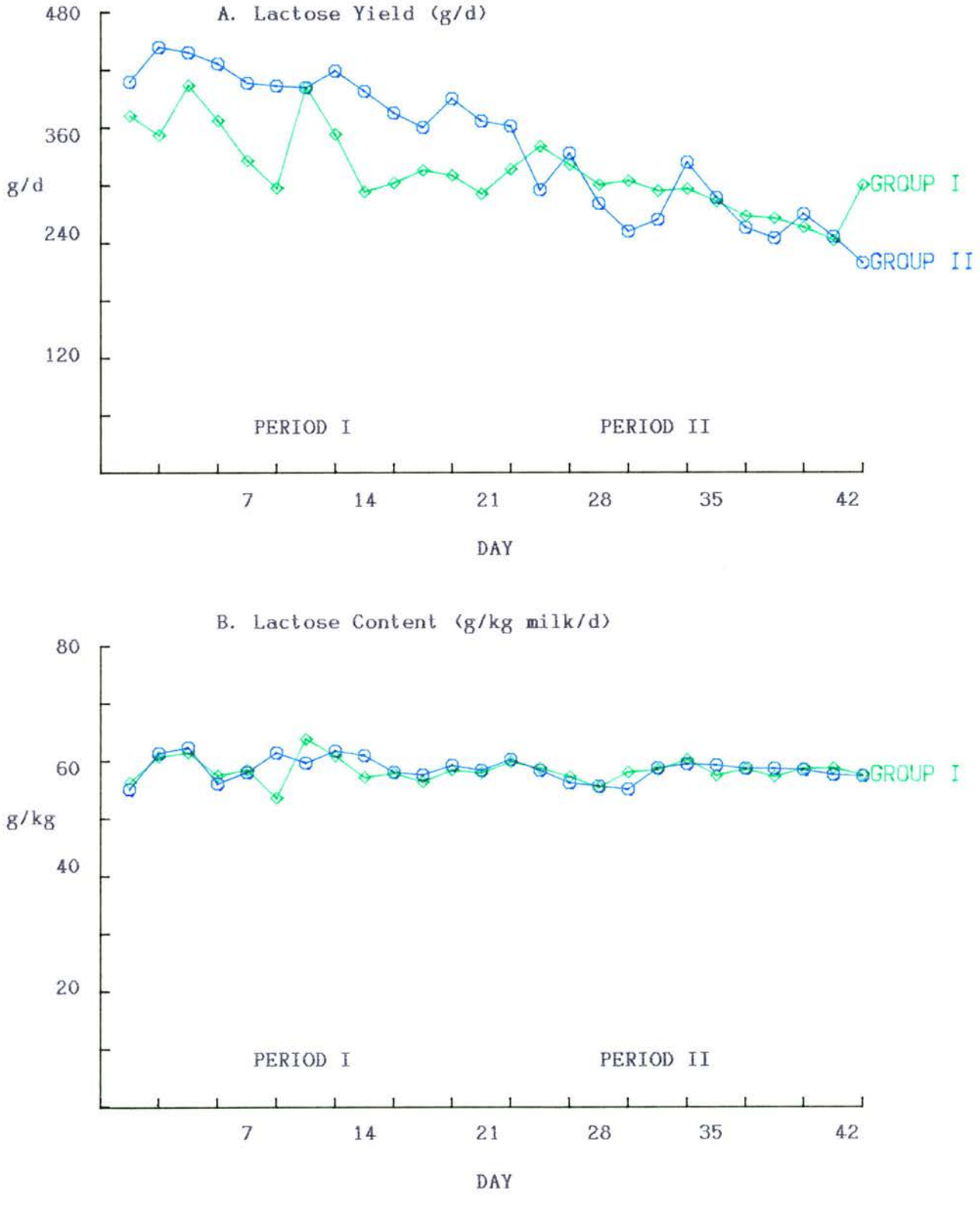


Figure 5.17. Variation in lactose yields (g/d) and lactose contents (g/kg milk/d) for animals in each group in Experiment II

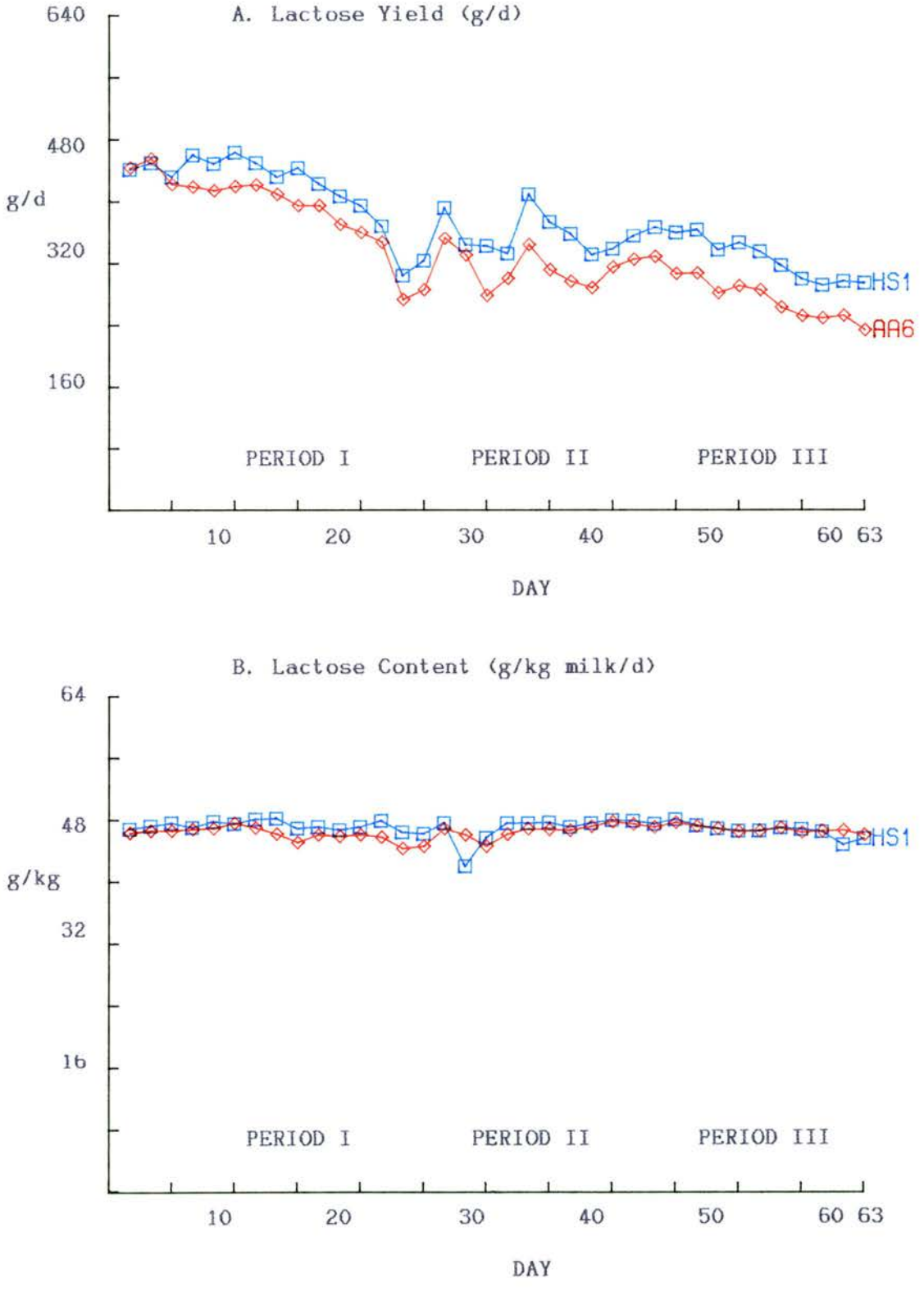


Figure 5.18. Variation in lactose yields (g/d) and lactose contents (g/kg milk/d) for animals in each group in Experiment III

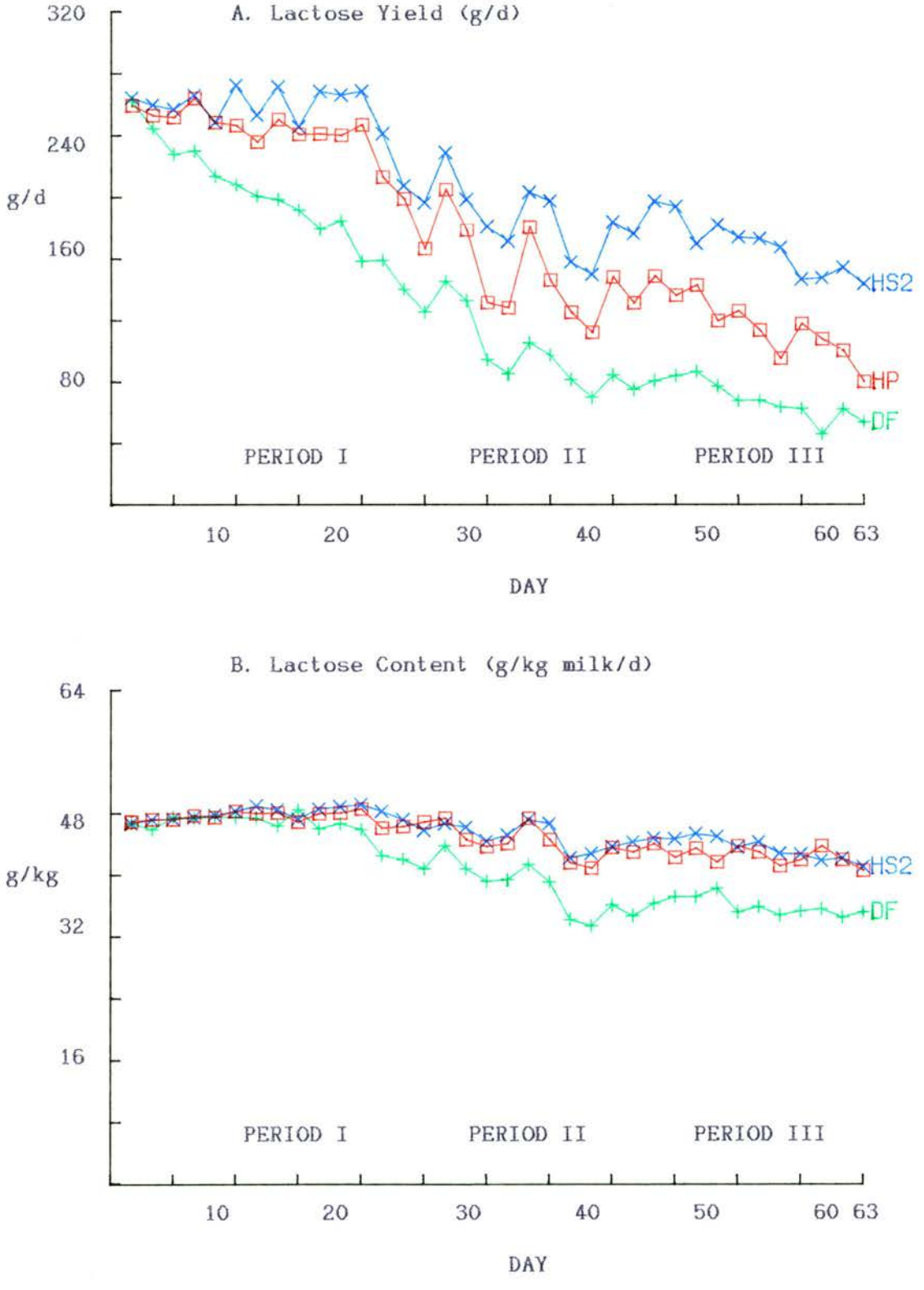
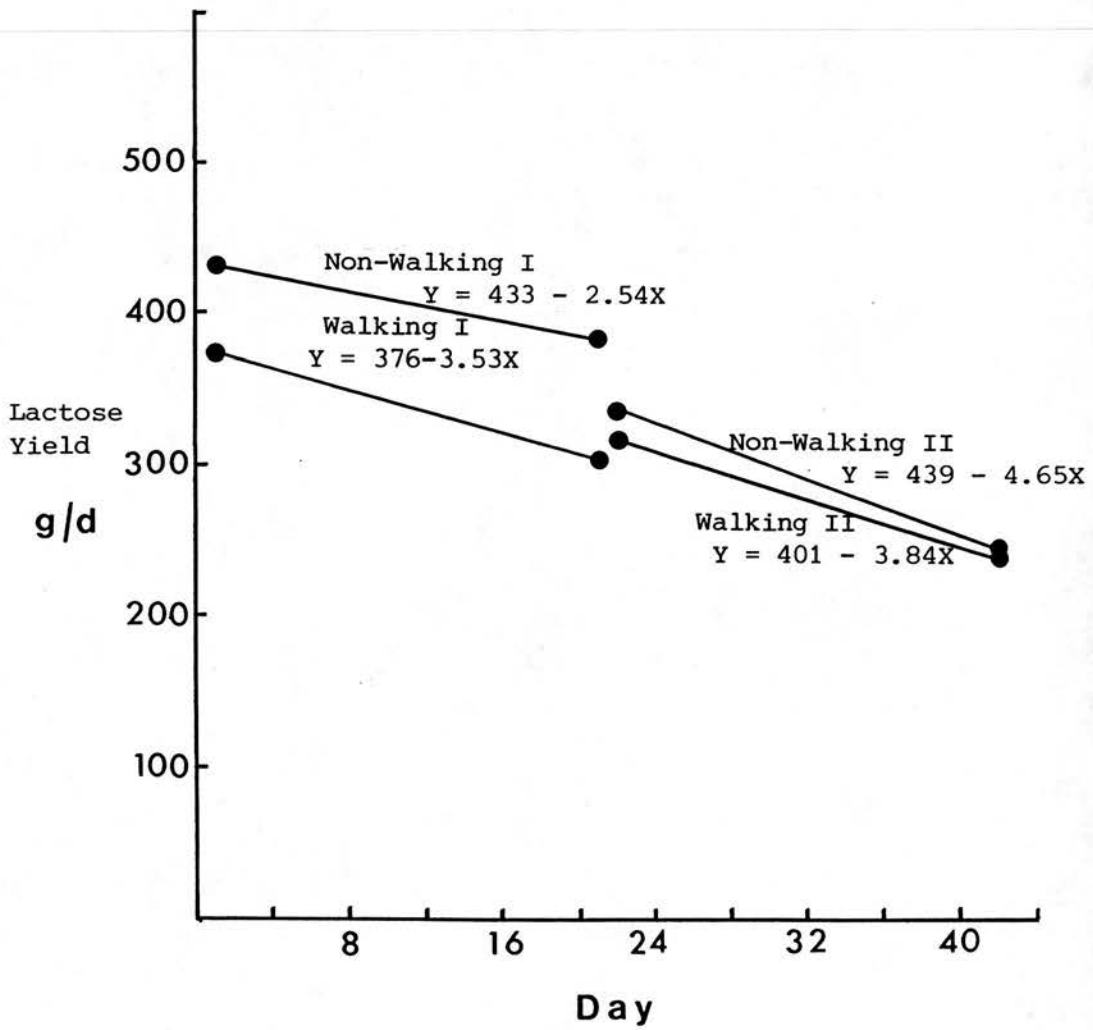


Figure 5.19. Fitted regression lines for lactose yields (g/d) for walking and non-walking groups in each period in Experiment I



5.2.3.2. THE EFFECT OF DIET ON LACTOSE CONTENT AND YIELD

In Experiment II diet did not have a significant effect on lactose content (g/kg milk/d) in either walking or non-walking groups. Significant differences ($p<0.001$) occurred between milk lactose contents resulting from diet DF in Experiment III in the non-walking and walking periods (Table 5.19). The lactose content resulting from diet DF was lower than for diets HS2 amnd HP (Table 5.21). Table 5.21 shows the mean lactose contents and yields for each diet in each experiment.

The differences between lactose yields resulting from the dietary treatments in both Experiments II and III were significant in the non-walking ($p<0.001$) and walking periods ($p<0.01$ and $p<0.001$) (Table 5.20). In Experiment II cows fed diet AA6 had persistently lower lactose yields than cows fed diet HS1 (Figure 5.17). In Experiment III the lactose yields of each diet were consistently different from each other and followed the pattern of milk yield changes (Figures 5.3 and 5.18).

There was no significant diet/exercise interaction which affected either lactose contents or yields. In Experiment II the difference between lactose yields in the milk of cows fed diets AA6 and HS1 in the walking period however, was less significant ($p<0.01$) than in the non-walking period ($p<0.001$). This was because the lactose yield as a result of diet HS1 declined less than the lactose yield of diet AA6 (Table 5.22).

Table 5.21. Mean lactose contents (g/kg) and yields (g/d) for each diet in each experiment

Experiment	Diet	Content (g/kg)	Yield (g)
I	AA6	58.7	327.6
II	AA6	46.9	330.5
	HS1	46.3	375.1
	SED	0.3	9.00
	p	ns	<0.001
III	HS2	45.2[a]	207.3
	DF	40.8[b]	123.0
	HP	45.0[a]	181.7
	SED	0.5	4.77
	p	<0.001[ab]	<0.001

In Experiment III the difference in lactose yields resulting from diets HP and HS2 was less significant in the walking period ($p<0.01$) than in the non-walking period ($p<0.001$). The lactose yield resulting from diet DF declined more than the yields resulting from diets HS2 and HP when animals walked (Table 5.22), though the significance of the difference between these diets was the same as in the non-walking period ($p<0.001$).

The proportional decreases in lactose content and yield between non-walking and walking groups for each diet are shown in Table 5.22.

Diet DF was associated with significantly lower ($p<0.001$) milk lactose contents than either of the other diets in Experiment III. When animals on this diet walked, the differences increased. The effect appeared to be related to the commencement of walking and was carried

through to the next non-walking period (Figure 5.18). This reduction in lactose content resulted in a considerably greater fall in lactose yield in the milk of animals fed the digestible fibre diet (Table 5.22), but this difference was not statistically significant.

Table 5.22. Proportional changes in lactose content (g/kg milk/d) and yield (g/d) when animals walked for each diet in Experiments I, II and III

Experiment	Diet	Proportional change	
		Content (g/kg milk/d)	Yield (g/d)
I	AA6	-0.01	-0.12
II	AA6	-0.01	-0.10
	HS1	-0.01	-0.08
III	HS2	-0.01	-0.10
	DF	-0.05	-0.22
	HP	-0.01	-0.12

5.2.4. SUMMARY OF RESULTS OF THE EFFECTS OF EXERCISE AND DIET ON MILK COMPOSITION AND CONSTITUENT YIELDS

- Milk fat content (g/kg) increased on all diets in each experiment when animals walked. Milk fat content showed an inverse relationship with milk yield, so that when milk yield declined, milk fat content increased.
- As a result of the increased fat content when milk yield declined due to exercise, the mean milk fat yield remained relatively constant and showed non-significant negative or positive changes (depending on diet) relative to non-walking means. On one diet (HP) a significant ($p<0.01$) increase was observed in milk fat yield when animals walked.
- Diet had a significant ($p<0.001$) effect on milk fat content and yield.

- Milk protein contents were not effected by exercise on any diet in any experiment. As daily milk yields decreased, milk protein synthesis decreased proportionately.

- Exercise had a negative effect on overall protein yields in all experiments ($p<0.01$). In Experiment II this effect was due mainly to the response of animals on diet HS2. Diets DF and HP in Experiment III resulted in no significant effect on milk protein yield when animals walked.

- Diet had a significant effect on milk protein contents and yields ($p<0.001$) except for differences between protein yields resulting from diets HS2 and HP, which were not significantly different.

- Exercise had a negative, but non-significant effect on lactose contents (g/kg milk/d) in the milk of animals fed all diets except diet DF, when the negative effect was significant ($p<0.001$). Exercise significantly depressed lactose yield (g/d) ($p<0/05$) for animals fed all diets in all experiments.

- All diets had a significant effect on lactose yields, but only diet DF significantly affected lactose content.

- The lowest declines when animals walked were in animals fed diets HS1 and HS2, followed by diets AA6 and HP. Diet DF was associated with the greatest lactose decline when animals walked.

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RESULTS:

THE EFFECT OF EXERCISE ON BLOOD METABOLITE CONCENTRATIONS

RESULTS

5.3. THE EFFECT OF EXERCISE ON BLOOD METABOLITE CONCENTRATIONS

Blood samples were taken once a week in Experiments II and III and were analysed for β-OH butyrate, urea, glucose, free fatty acids, globulin, albumin, magnesium and inorganic phosphorus (Section 4.4.2). Normal concentrations for blood metabolites for suckler cows (Dairy Herd Health and Productivity Service figures) and cattle in general (Collins and Kelly, 1977; Swaid *et al*, 1986) are given in Appendix 4A. Mean values for metabolite concentrations for each cow for each week in Experiments II and III are presented in Appendices 4B and 4C.

5.3.1. β-OH BUTYRATE

In both experiments, serum β-OH butyrate concentrations increased significantly ($p<0.001$) when animals walked (Table 5.23 and Figure 5.20). Mean proportional increases were 0.60 (Experiment II) and 1.42 (Experiment III).

The concentrations during the non-walking periods in each experiment were within the normal ranges (0.24 to 0.96 mmol/l) for suckler cows, but non-walking concentrations in Experiment II were at the upper limits of the normal range and were higher than the non-walking concentrations in Experiment III, which were well within the normal range. The concentrations measured on all diets when animals walked were higher than the normal range. Concentrations in mid to late lactation are normally lower than in early lactation (see Appendix 4A) and the cows in the present experiments would be expected to be at the

lower end of the range.

Diet had a significant effect on β-OH butyrate concentrations. In the walking periods of both experiments, differences in β-OH butyrate concentrations of cows on the different diets were significant ($p<0.05$) (Table 5.23). Diet did not have a significant effect on concentrations in the non-walking periods. Hence there was a significant diet/exercise interaction ($p<0.01$ for Experiment II and $p<0.05$ for Experiment III) which affected β-OH butyrate levels when animals walked.

In Experiment II the increase in the walking period was greatest for cows fed diet AA6 compared with cows fed diet HS1 (0.83 compared with 0.37 respectively). In Experiment III increases during the walking period for cows fed diets HS2, DF and HP were 1.09, 1.40 and 1.73 greater than concentrations in the non-walking period for each diet respectively. Cows fed diets HP and DF had significantly higher blood concentrations than cows fed diet HS2 in the walking period ($p<0.01$ and $p<0.05$ respectively), which is consistent with Experiment II.

In Experiment II the greatest effect of exercise was recorded in the first walking week, but in Experiment III the greatest effect of walking was recorded in week two. This difference in the response applies also to the other metabolites described later. In Experiment III cows were introduced to exercise more gradually than in Experiment II because they were older and this probably explains the relative difference in response in week one of each experiment.

Table 5.23. Mean serum β-OH Butyrate concentrations (mmol/l) for walking and non-walking groups for each diet in Experiments II and III

Experiment II

	Not-Walking	Walking	SED	
AA6	0.80a	1.46b	0.07	
HS1	0.81a	1.11c	0.07	
SED	0.10	0.12		
n	36	18		
Total	0.80	1.29	0.05	(p<0.001)

bc = p<0.05; ab, ac = p<0.001.

Experiment III

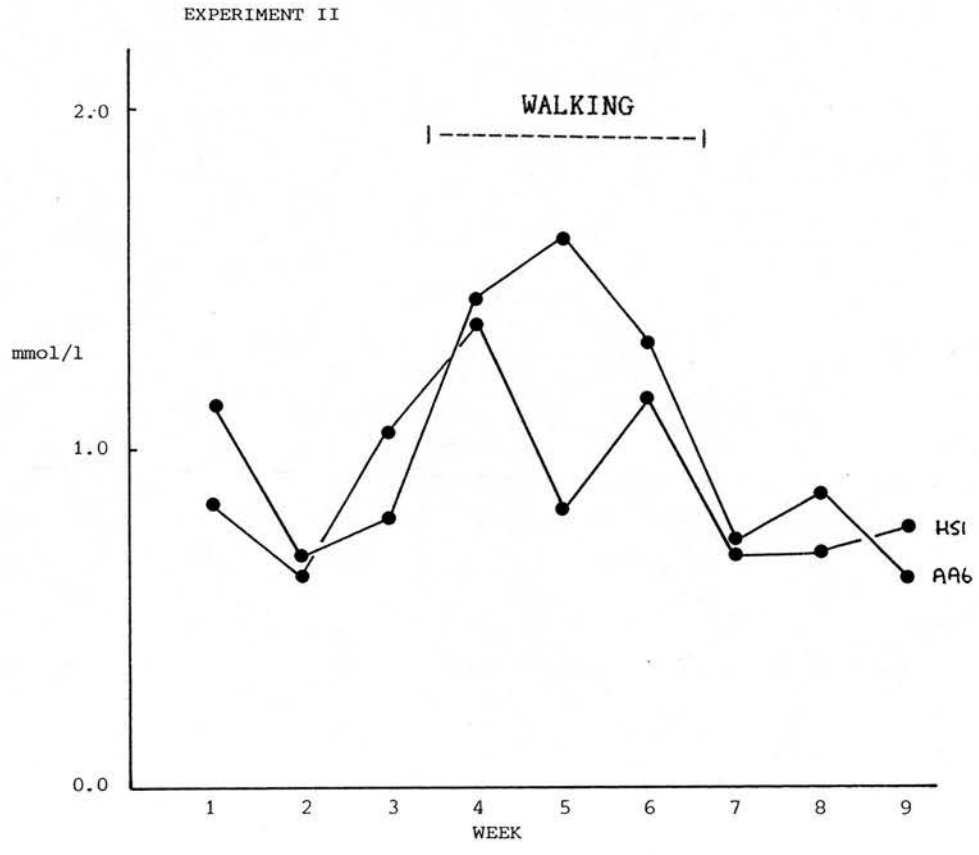
	Not-Walking	Walking	SED	
HS2	0.43a	0.90b	0.08	
DF	0.51a	1.22c	0.08	
HP	0.51a	1.39c, d	0.08	
SED	0.10	0.12		
n	24	12		
Total	0.48	1.17	0.05	(p<0.001)

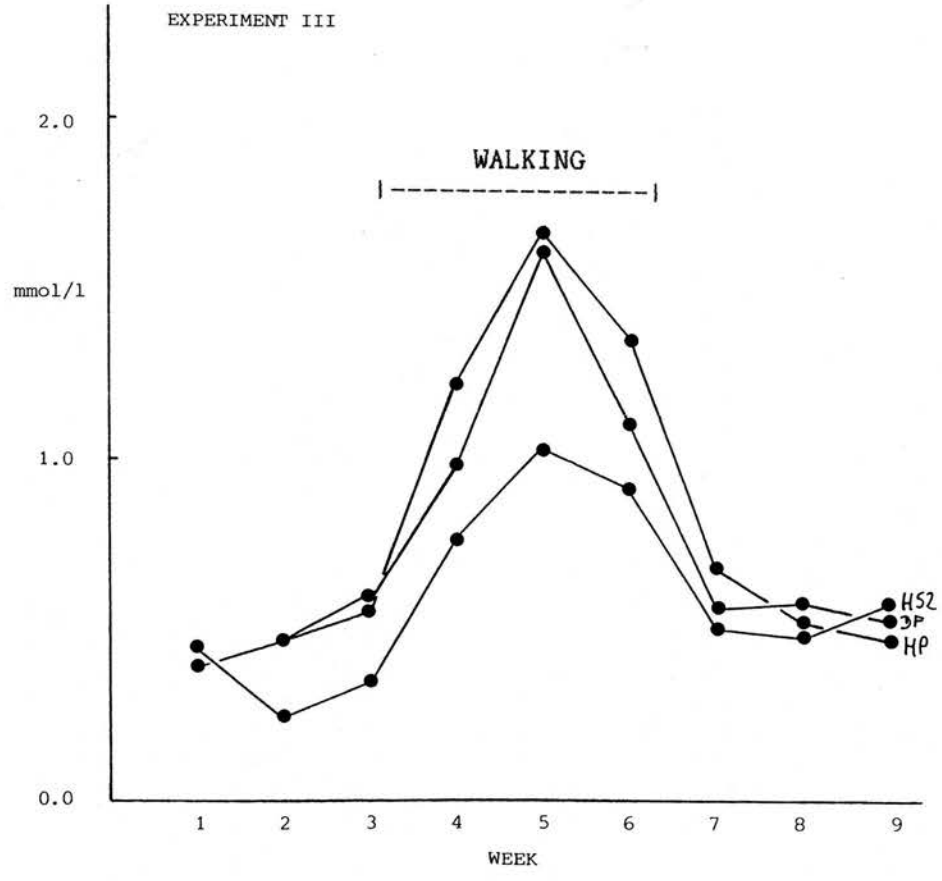
bc = p<0.05; bd = p<0.01; ab, ac = p<0.001.

NB. Means with the same subscript in either row or column are not statistically significantly different

SED = Standard Error of the Difference between means

Figure 5.20. Variation in serum β-OH butyrate concentrations (mmol/l) for animals fed each diet in Experiments II and III





5.3.2. GLUCOSE

In both experiments a significant ($p<0.001$) decrease in plasma glucose concentration occurred when animals walked (Table 5.24 and Figure 5.21). Mean proportional decreases were 0.09 in both Experiments II and III.

The fall in glucose concentration was greater in the earlier part of walking period in Experiment II than later in the period when a partial recovery was observed. Similarly, in Experiment III a recovery was observed in week three. The fall was more pronounced in the first walking week of Experiment II compared with the first walking week in Experiment III. The cows were older in Experiment III and were introduced to exercise more slowly than in Experiment II, which may have resulted in a lower response in the first walking week in Experiment III.

Diet had no statistically significant effect on the glucose concentrations in either Experiment II or III and there was no significant diet/exercise interaction. The proportional declines in glucose concentrations for cows fed on each diet when animals walked were 0.08 (AA6), 0.11 (HS1), 0.07 (HS2), 0.10 (DF) and 0.10 (HP). These differences were not statistically significant.

The non-walking concentrations were higher than the normal range (3.05 to 3.49 mmol/l) for suckler cows. When animals walked, the mean concentrations, although lower, were still above the normal range in Experiment II, but towards the lower end of the normal range in Experiment III. The mean value only went below the normal range (3.05mmol/l) on one occasion in Experiment II, when a mean value of

Table 5.24. Mean plasma glucose concentrations (mmol/l) for walking and non-walking groups for each diet in Experiments II and III

Experiment II

	Not-Walking	Walking	SED	
AA6	3.89a	3.58b	0.10	
HS1	3.98a	3.56b, c	0.10	
SED	0.12	0.14		
n	36	18		
Total	3.93	3.57	0.07	(p<0.001)

ab = p<0.01; ac = p<0.001.

Experiment III

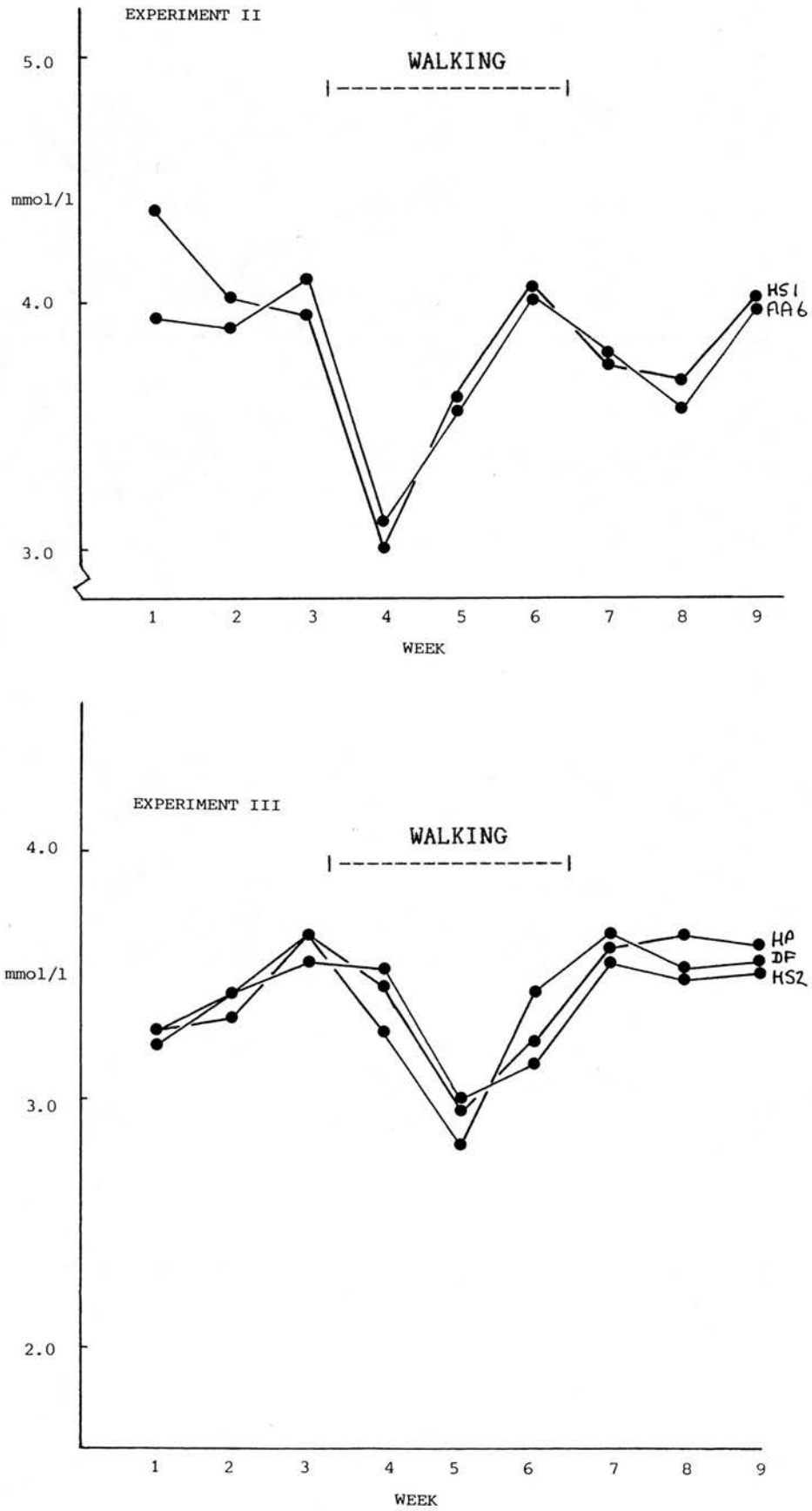
	Not-Walking	Walking	SED	
HS2	3.47a	3.22b	0.08	
DF	3.50a	3.17b, c	0.08	
HP	3.57a	3.23b, c	0.08	
SED	0.11	0.13		
n	24	12		
Total	3.51	3.21	0.04	(p<0.001)

ab = p<0.01; ac = p<0.001.

NB. Means with the same subscript in either row or column are not statistically significantly different

SED = Standard Error of the Difference between means

Figure 5.21. Variation in mean plasma glucose concentrations (mmol/l) for animals fed each diet in Experiments II and III



3.01 mmol/l was recorded in the first walking week for cows fed diet HS1, and on one occassion in Experiment III when values in the second walking week for cows on all diets were low (3.00 (HS2), 2.82 (DF) and 2.98 mmol/l (HP)) (Appendix 4B and 4C).

5.3.3. UREA

The effect of exercise on plasma urea concentration was inconclusive (Figure 5.22). Urea concentrations in the non-walking periods were within the normal range (1.57 to 3.23 mmol/l) for suckler cows, for cows fed diets AA6, HS1, HS2 and DF, but were above the normal range for cows fed diet HP. When animals walked, the concentrations for cows fed diets HS1 and HP were also above the normal range for urea concentrations in suckler cows.

In Experiment II urea concentrations rose significantly ($p<0.001$) on both diets when the animals walked (0.15 compared with 0.18 for cows fed on AA6 and HS1 diets respectively). Concentrations decreased slightly, but not significantly, on two diets (HS2 and DF) in Experiment III when animals walked (Table 5.25). Concentrations increased significantly ($p<0.05$) by 0.11 in the walking period on diet HP in Experiment III, and remained relatively high in the second control period compared with the first control period.

The only dietary effects were in Experiment III in which urea concentrations on diet HP were significantly higher ($p<0.001$) than diets HS2 and DF. There was no diet/exercise interaction.

Table 5.25. Mean plasma urea concentrations (mmol/l) for walking and non-walking groups for each diet in Experiments II and III

Experiment II

	Not-Walking	Walking	SED
AA6	2.78a	3.20b	0.11
HS1	2.90a	3.43b	0.11
SED	0.19	0.21	
n	36	18	
Total	2.84	3.32	0.08 (p<0.001)

ab = p<0.001.

Experiment III

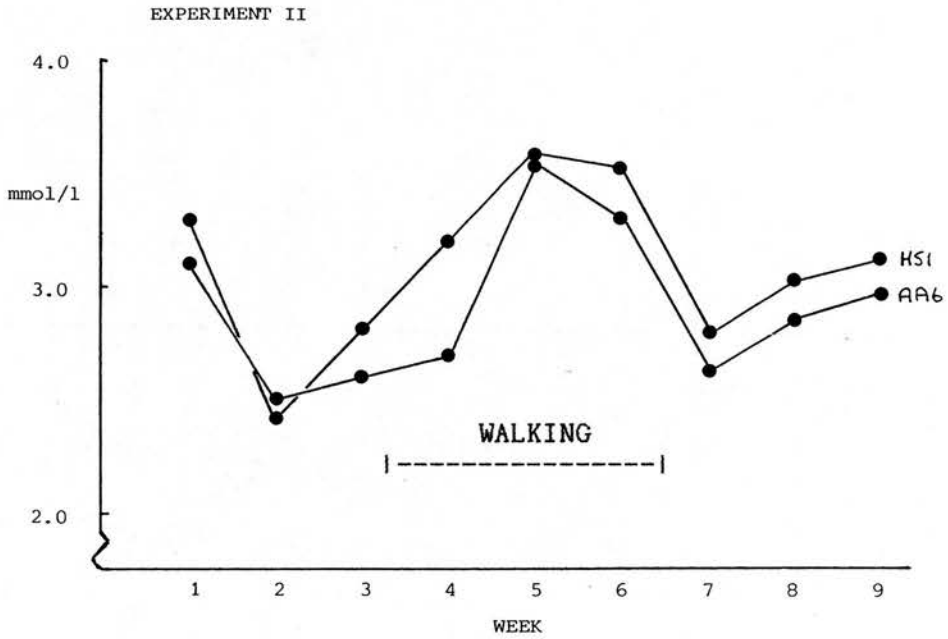
	Not-Walking	Walking	SED
HS2	3.05a	2.84a	0.20
DF	3.04a	2.91a	0.20
HP	4.57b	5.07c	0.20
SED	0.23	0.29	
n	24	12	
Total	3.55	3.61	0.12 ns

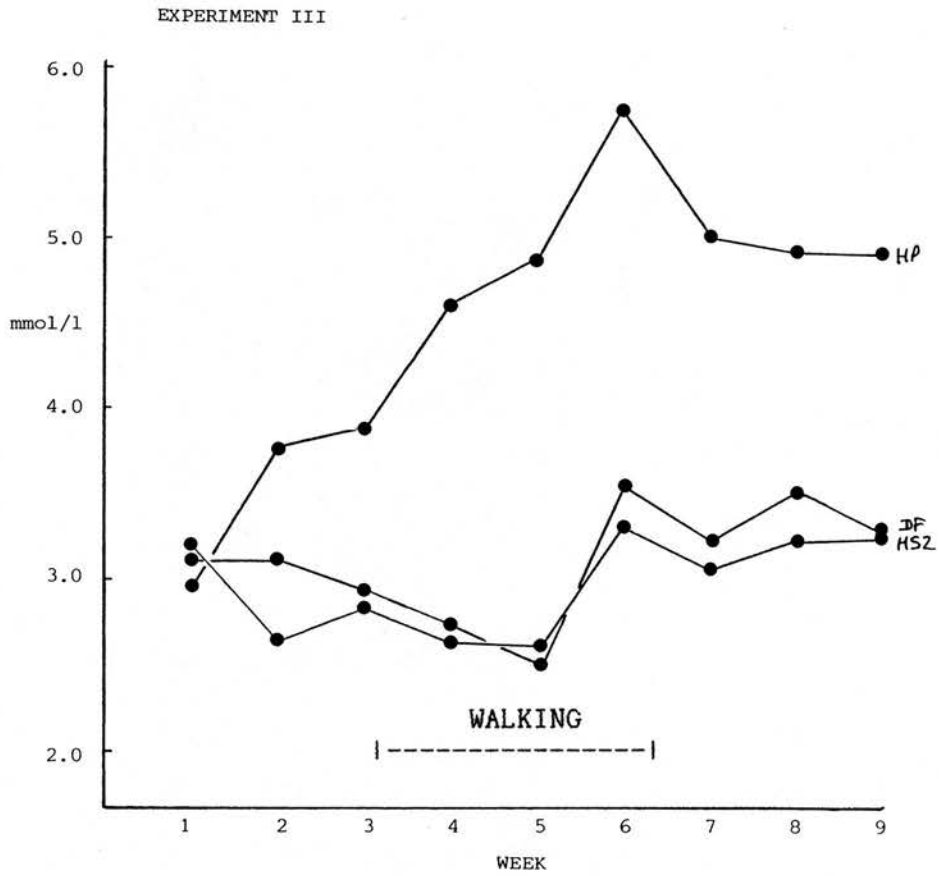
ab, ac = p<0.001; bc = p<0.05.

NB. Means with the same subscript in either row or column are not statistically significantly different

SED = Standard Error of the Difference between means

Figure 5.22. Variation in mean plasma urea concentrations (mmol/l) for animals fed each diet in Experiments II and III





5.3.4. FREE FATTY ACIDS

Although results for free fatty acids were incomplete in Experiment II as a result of laboratory error, concentrations of free fatty acids rose during the walking periods of both experiments (Figure 5.23). The mean proportional increase when animals walked in Experiment II was 7.14 compared with 0.58 when animals walked in Experiment III. The increase in Experiment III was significant ($p<0.001$; Table 5.26).

Diet had no significant effect on free fatty acid concentrations and there was no diet/exercise interaction.

In Experiment III increases in the walking period for animals which received diets HS2, DF and HP were 0.98, 0.45 and 0.35 respectively of non-walking values. Only the difference for animals receiving diet HS2 was significant ($p<0.001$) (Table 5.26).

In Experiment II mean concentrations were below the normal range given by Collins and Kelly (1977) (0.614 to 0.784 mequiv/l), but were higher than normal when animals walked (Appendix 4B). In Experiment III concentrations were within the normal range for animals fed each diet in the non-walking period, but mean values for animals fed each diet were above the normal range when animals walked.

In Experiment II mean levels were approximately twice as high for animals receiving diet AA6 compared with those receiving diet HS1 in the walking period, but since the data were incomplete, a proper analysis could not be carried out. In Experiment III, although animals receiving diet HS2 had higher concentrations than animals receiving diets HP and DF, the differences were not significant.

Table 5.26. Mean serum free fatty acid concentrations (meq/l) for walking and non-walking groups for each diet in Experiment III

Experiment III

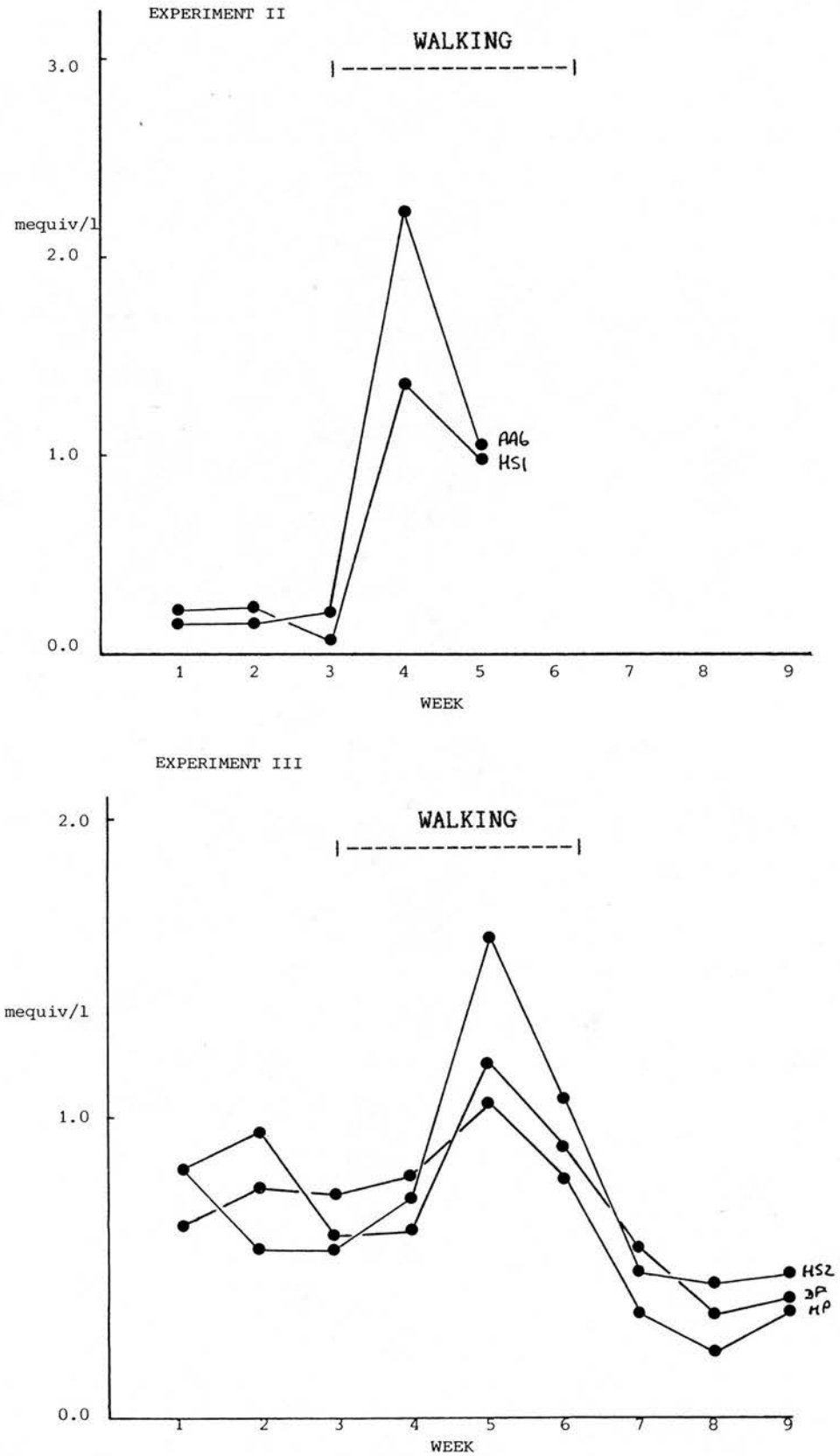
	Not-Walking	Walking	SED
HS2	0.56a	1.12b	0.14
DF	0.62a	0.90a, b	0.14
HP	0.64a	0.87a, b	0.14
SED	0.13	0.17	
n	24	12	
Total	0.61	0.96	0.08 (p<0.001)

ab = p<0.001.

NB. Means with the same subscript in either row or column are not statistically significantly different

SED = Standard Error of the Difference between means

Figure 5.23. Variation in mean serum free fatty acid concentrations (mequiv/l) for animals fed each diet in Experiments II and III



5.3.5. ALBUMIN

Walking had a significant effect on serum albumin concentrations in both experiments, but the effects were opposite (Table 5.27 and Figure 5.24). In Experiment II concentrations increased, but the increase was only significant ($p<0.05$) for diet AA6. In Experiment III concentrations decreased on all diets ($p<0.01$).

Significant variations ($P<0.05$) occurred between animals receiving diets AA6 and HS1 in Experiment II and diets HS2 and HP in Experiment III. The high starch diet was associated with the lowest concentrations in both cases. Concentrations for animals on all diets, whether walking or non-walking, were within the normal range (2.90 to 3.90 g%) for suckler cows.

5.3.6. GLOBULIN

Neither diet nor exercise had a significant effect on concentrations of serum globulin in either Experiment II or III (Table 5.28 and Figure 5.25). In Experiment III concentrations were lower during the walking period ($p<0.05$), but the differences were not significant for individual diets. Concentrations for animals on all diets whether walking or non-walking, were within the normal range (3.10 to 5.50 g%) for suckler cows.

5.3.7. INORGANIC MAGNESIUM

There was some concern at the beginning of both experiments that the concentrations of magnesium were at the low end of the normally expected range for suckler cows in mid-lactation (eg. 2.0 to 3.0

Table 5.27. Mean serum albumin concentrations (g%) for walking and non-walking groups for each diet in Experiments II and III

Experiment II

	Not-Walking	Walking	SED	
AA6	3.13a	3.32b	0.07	
HS1	2.99a	3.10b, a	0.07	
SED	0.07	0.09		
n	36	18		
Total	3.06	3.21	0.05	($p<0.01$)

ab = $p<0.05$.

Experiment III

	Not-Walking	Walking	SED	
HS2	3.32a	3.15b	0.05	
DF	3.42a	3.26b, c	0.05	
HP	3.50a	3.41c	0.05	
SED	0.08	0.09		
n	24	12		
Total	3.42	3.28	0.02	($p<0.001$)

bc = $p<0.05$; ac, ab = $p<0.01$.

NB. Means with the same subscript in either row or column are not statistically significantly different

SED = Standard Error of the Difference between means

Figure 5.24. Variation in mean serum albumin concentrations (g%) for animals fed on each diet in Experiments II and III

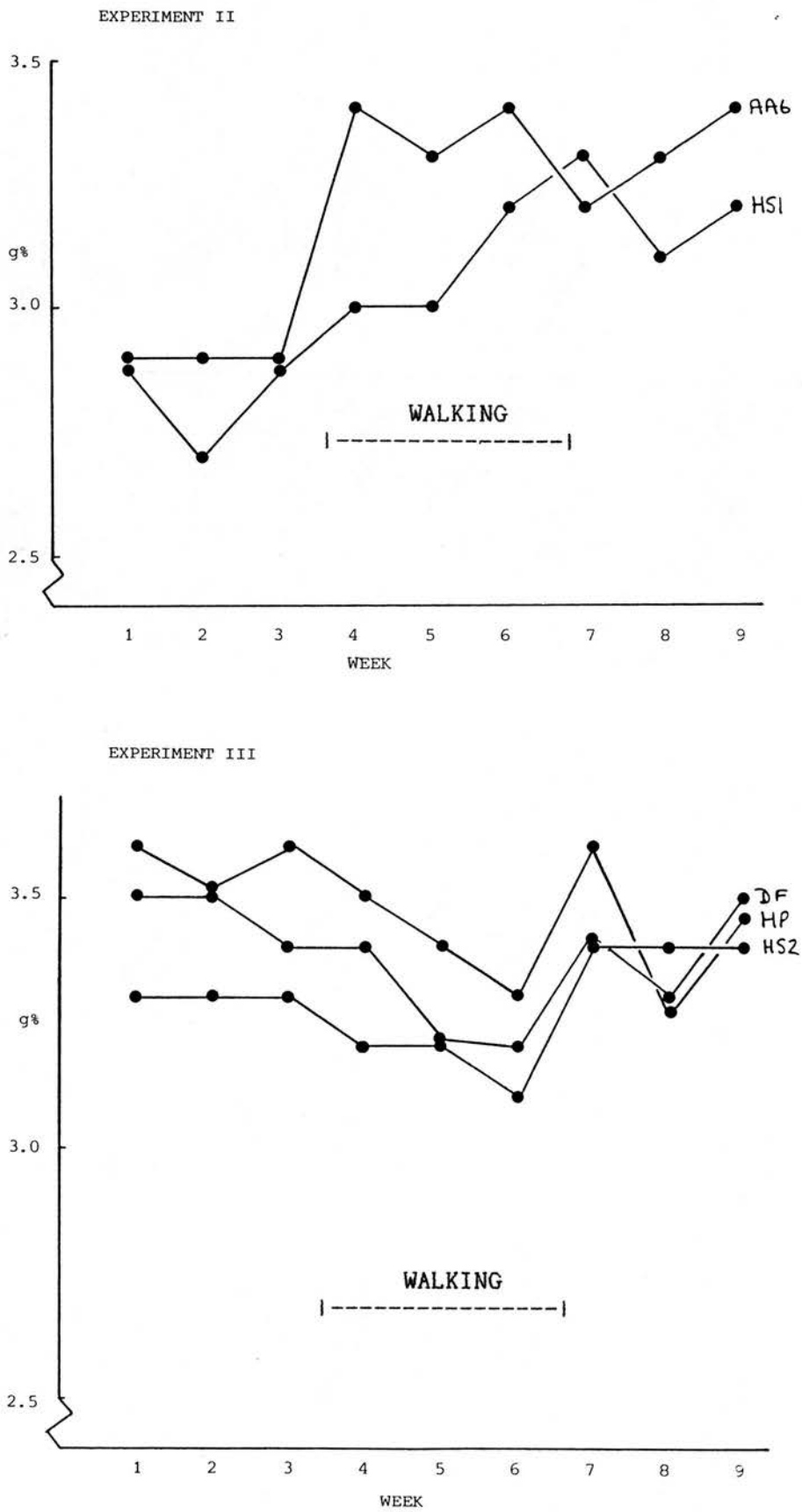


Table 5.28. Mean serum globulin concentrations (g%) for walking and non-walking groups for each diet in Experiments II and III

Experiment II

	Not-Walking	Walking	SED
AA6	4.22a	4.14a	0.11
HS1	4.52a	4.44a	0.11
SED	0.18	0.21	
n	36	18	
Total	4.37	4.29	0.08 ns

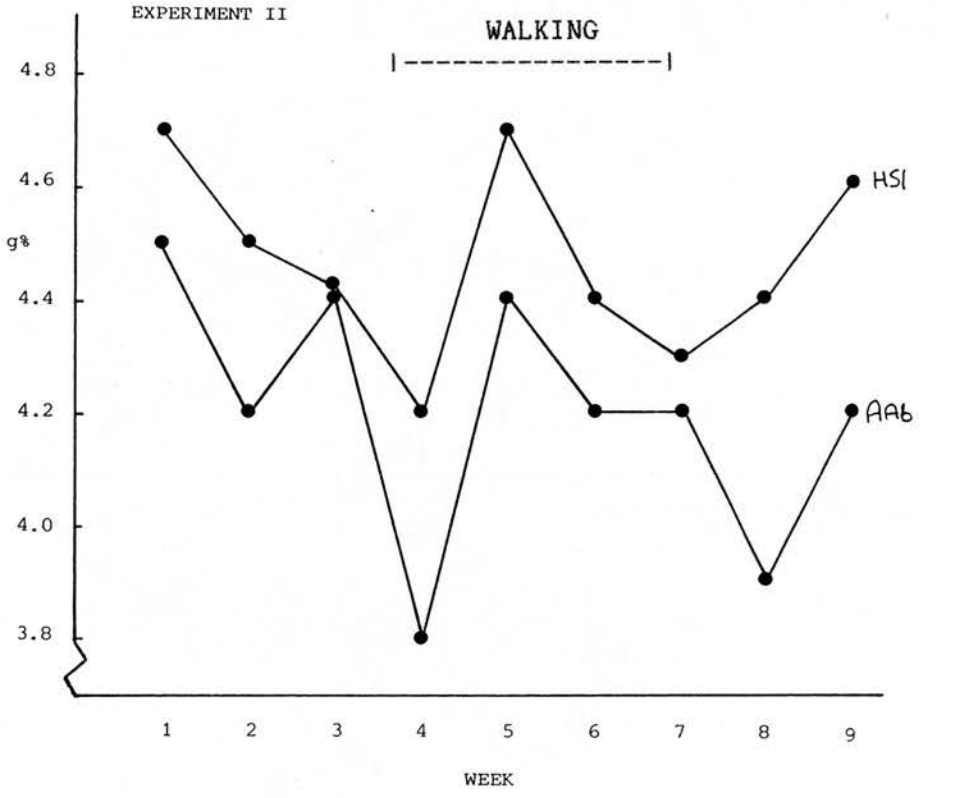
Experiment III

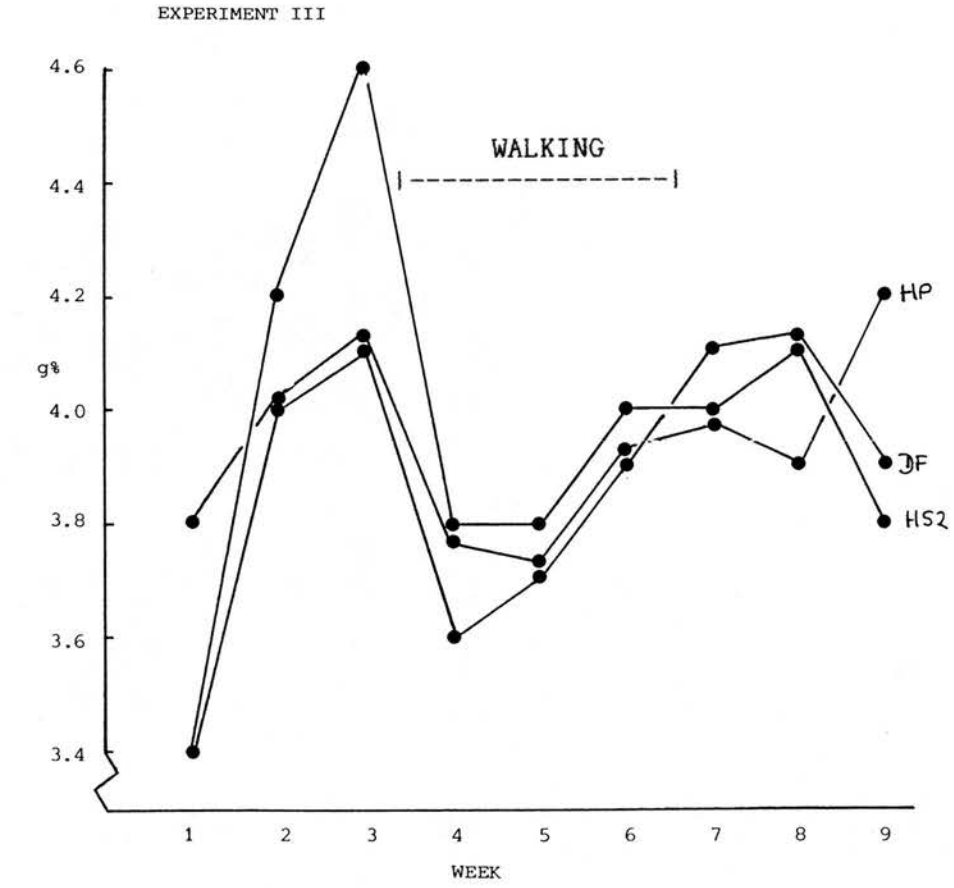
	Not-Walking	Walking	SED
HS2	4.01a	3.89a	0.12
DF	3.92a	3.71a	0.12
HP	3.97a	3.80a	0.12
SED	0.20	0.22	
n	24	12	
Total	3.97	3.80	0.07 ($p<0.05$)

NB. Means with the same subscript in either row or column are not statistically significantly different

SED = Standard Error of the Difference between means

Figure 5.25. Variation in mean serum globulin concentrations (g%) for animals fed each diet in Experiments II and III





mg/100ml; Appendix 4A). The animals were supplemented with calcined magnesite (20g/d), but showed no signs of hypomagnesaemia.

In Experiment II there were neither statistically significant dietary nor exercise effects on serum magnesium concentrations (Figure 5.26; Table 5.29) and serum concentrations were well within the normal range in both walking and non-walking periods. There was an indication of a decrease in concentration when animals walked in animals fed both diets, and concentrations were higher in the last non-walking period than in either the first non-walking period or the walking period.

In Experiment III however, there were both dietary and exercise effects on serum magnesium concentrations, which are shown in Figure 5.26. Exercise significantly ($p<0.001$) depressed concentrations on all diets and concentrations in animals on all diets were below the normal range (2.00 to 3.00 mg/100ml) when they walked.

Diet had a significant effect on concentrations during the walking period ($p<0.05$), but had no significant effect on concentrations during the non-walking periods. Concentrations of cows fed diet HP were significantly lower ($p<0.05$) than concentrations for cows fed diets DF and HS2 in the walking period (Table 5.29 and Figure 5.27).

5.3.8. INORGANIC PHOSPHORUS

Plasma phosphorus concentrations were within the normal range (4.3 to 7.7 mg/100ml), but were lower in Experiment III than in Experiment II (Figure 5.28). Exercise significantly depressed phosphorus concentrations in both Experiment II and III ($p<0.001$; Table 5.30) and mean concentrations were below the normal range for cows fed diets HS2 and DF in Experiment III when animals walked.

Table 5.29. Mean serum magnesium concentrations (mg/100ml) for walking and non-walking groups for each diet in Experiments II and III

Experiment II

	Not-Walking	Walking	SED
AA6	2.16a	2.05a	0.08
HS1	2.38a	2.28a	0.08
SED	0.11	0.13	
n	36	18	
Total	2.27	2.16	0.05 (ns)

Experiment III

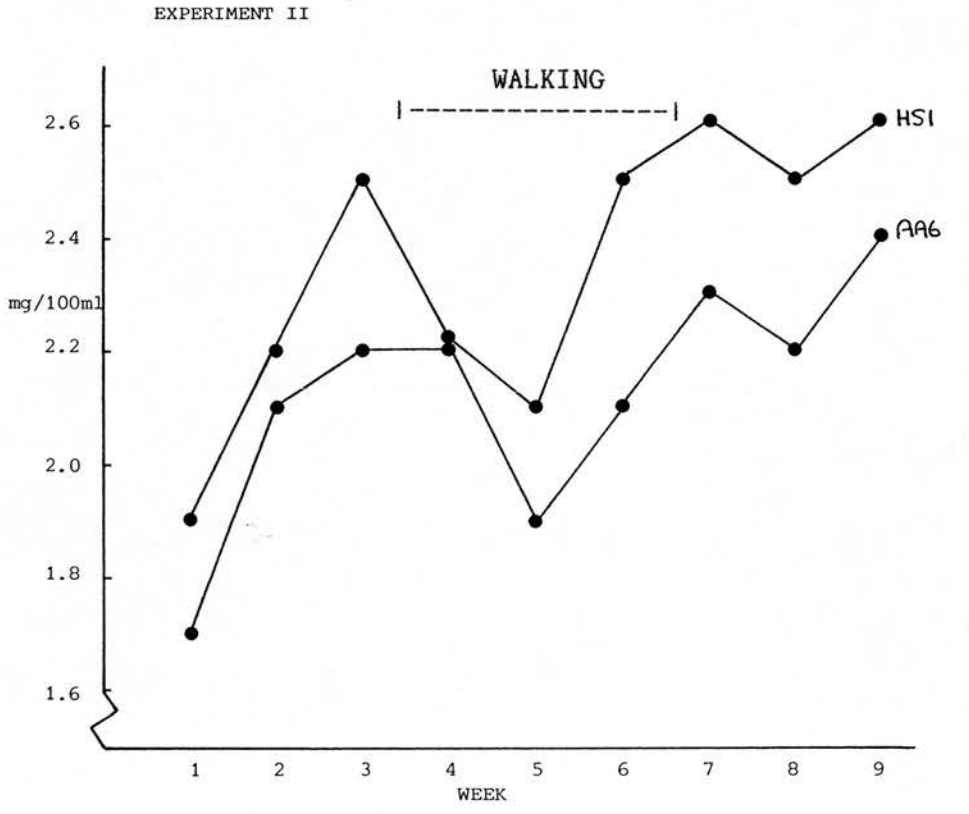
	Not-Walking	Walking	SED
HS2	2.18a	1.93b, c	0.05
DF	2.22a	1.96b	0.05
HP	2.00a	1.70c	0.05
SED	0.10	0.11	
n	24	12	
Total	2.13	1.86	0.03 ($p<0.001$)

ab, ac = $p<0.001$; bc = $p<0.05$.

NB. Means with the same subscript in either row or column are not statistically significantly different

SED = Standard Error of the Difference between means

Figure 5.26. Variation in mean serum magnesium concentrations (mg/100ml) for animals fed each diet in Experiments II and III



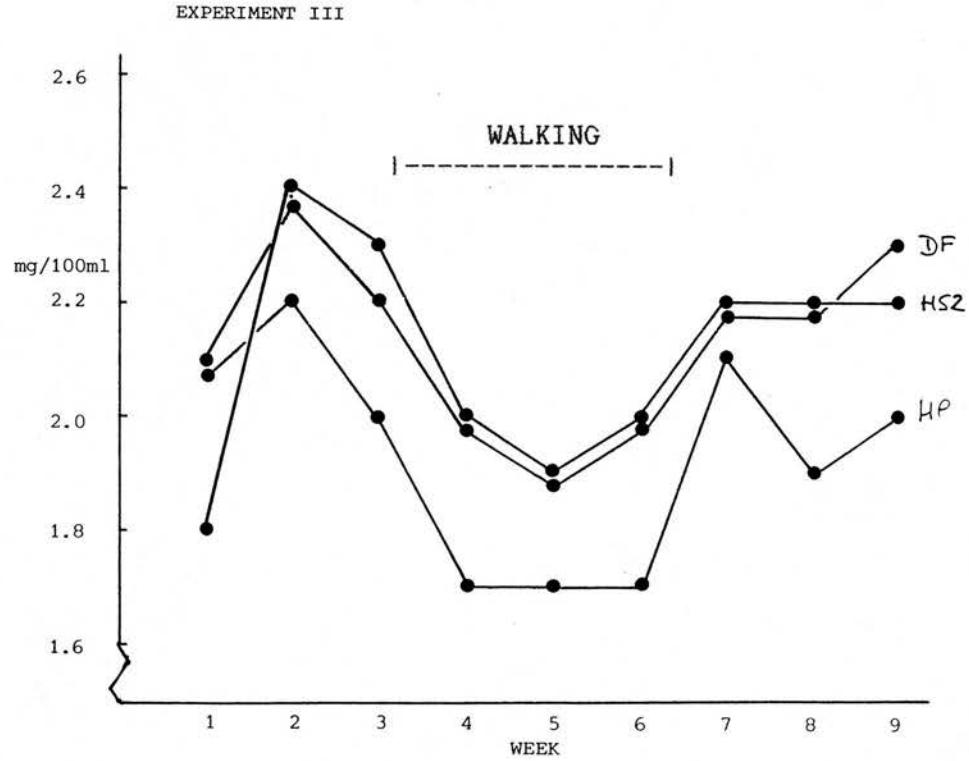


Table 5.30. Mean plasma inorganic phosphorus concentrations (mg/100ml) for walking and non-walking groups for each diet in Experiments II and III

Experiment II

	Not-Walking	Walking	SED
AA6	7.50a	5.91b, c	0.37
HS1	7.16a	6.49a, b	0.37
SED	0.05	0.06	
n	36	18	
Total	7.33	6.20	0.26 (p<0.001)

ac = p<0.001.

Experiment III

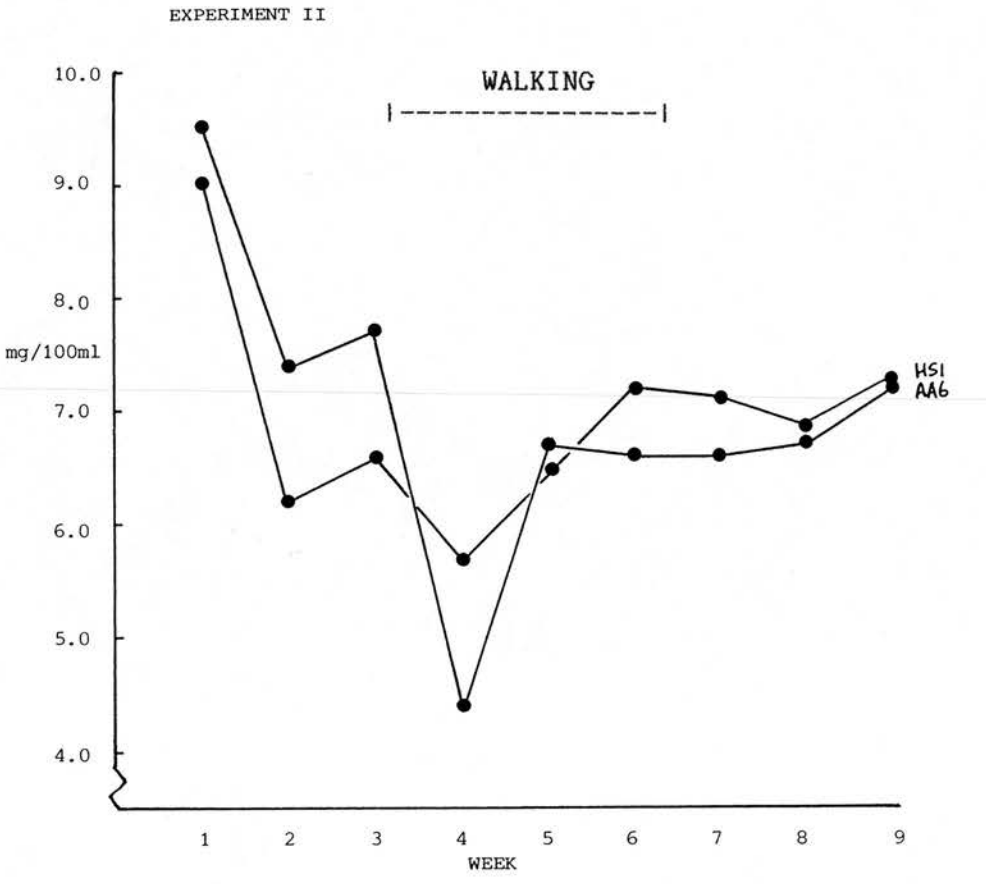
	Not-Walking	Walking	SED
HS2	6.50a	3.60b	0.30
DF	5.68a	3.61b	0.30
HP	6.62a	5.50c	0.30
SED	0.59	0.64	
n	24	12	
Total	6.27	4.24	0.17 (p<0.001)

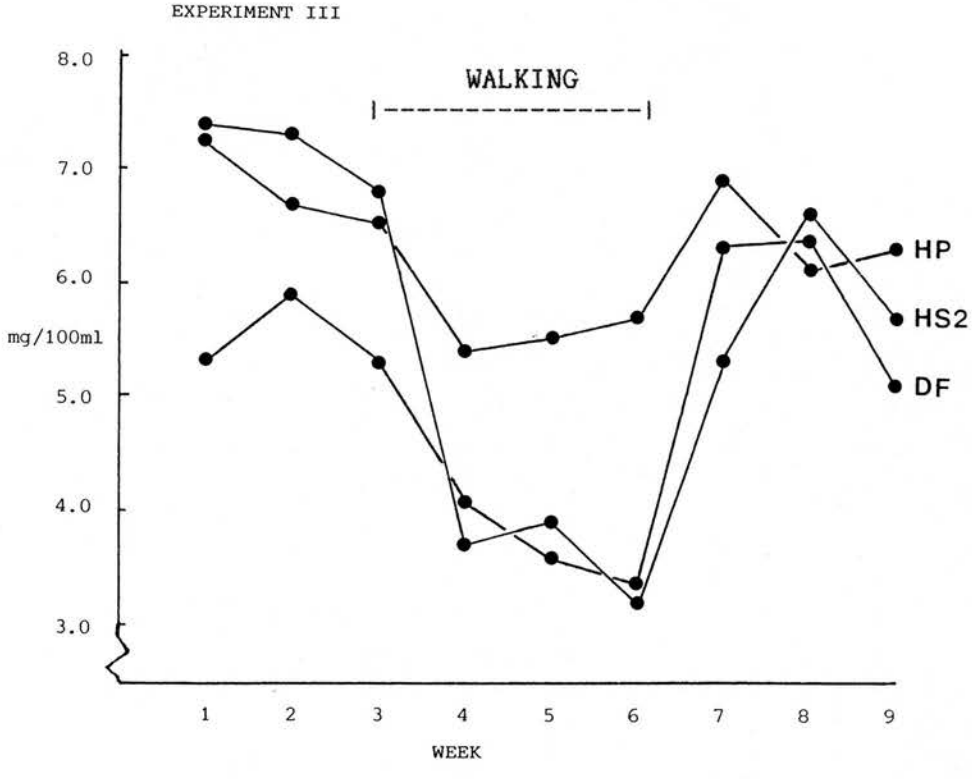
ab, ac = p<0.001; bc = p<0.05.

NB. Means with the same subscript in either row or column are not statistically significantly different

SED = Standard Error of the Difference between means

Figure 5.27. Variation in mean plasma inorganic phosphorus concentrations (mg/100ml) for animals fed each diet in Experiments II and III





There were no statistically significant differences due to diet in Experiment II, but significant dietary differences were seen in Experiment III in the walking period in which concentrations in animals receiving diet HP were significantly higher ($P<0.05$) than concentrations in animals receiving diets HS2 and DF. Thus a significant ($p<0.01$) diet/exercise interaction occurred which caused plasma phosphorus concentrations to decline in animals receiving some diets, but not on others, when animals walked.

5.3.9. DURATION OF THE RESPONSES

The responses of blood metabolite concentrations to exercise were usually greater in the first week of exercise (Experiment II) and the second week of exercise (Experiment III) than in subsequent weeks. Glucose and β-OH butyrate in particular showed a lesser response in the last week of exercise.

Since blood samples were only taken once a week, it was difficult to estimate the duration of the response. Serial samples throughout a 24 hour period were not possible, but it was possible to take additional samples on the non-walking days at the end of one walking week. Thus in Experiment III, additional samples were taken at the normal sampling time (14.00h) for three days (the last walking day and the following two non-walking days) at the end of the second walking week. The values for these days are shown in Appendix 4D. Concentrations had usually returned to non-walking levels by the time of sampling on the first non-walking day, and all levels had returned to non-walkimng levels by the time of sampling on the second non-walking day.

The durations of the responses in blood metabolite concentrations were therefore short, and levels had usually returned to normal within 24 hours of exercise.

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RESULTS:

THE EFFECT OF EXERCISE ON BODY WEIGHT CHANGES

RESULTS

5.4. BODY WEIGHT CHANGES

The animals usually were weighed twice a week on Mondays and Thursdays at 10.00h after milking and before walking. A weigh bridge was permanently available in the barn. The weights of each cow in each experiment on day one of the first period (mean of the previous four weighings) are shown in Appendix 2B and the weights for each cow at each weighing in each experiment are shown in Appendix 5.

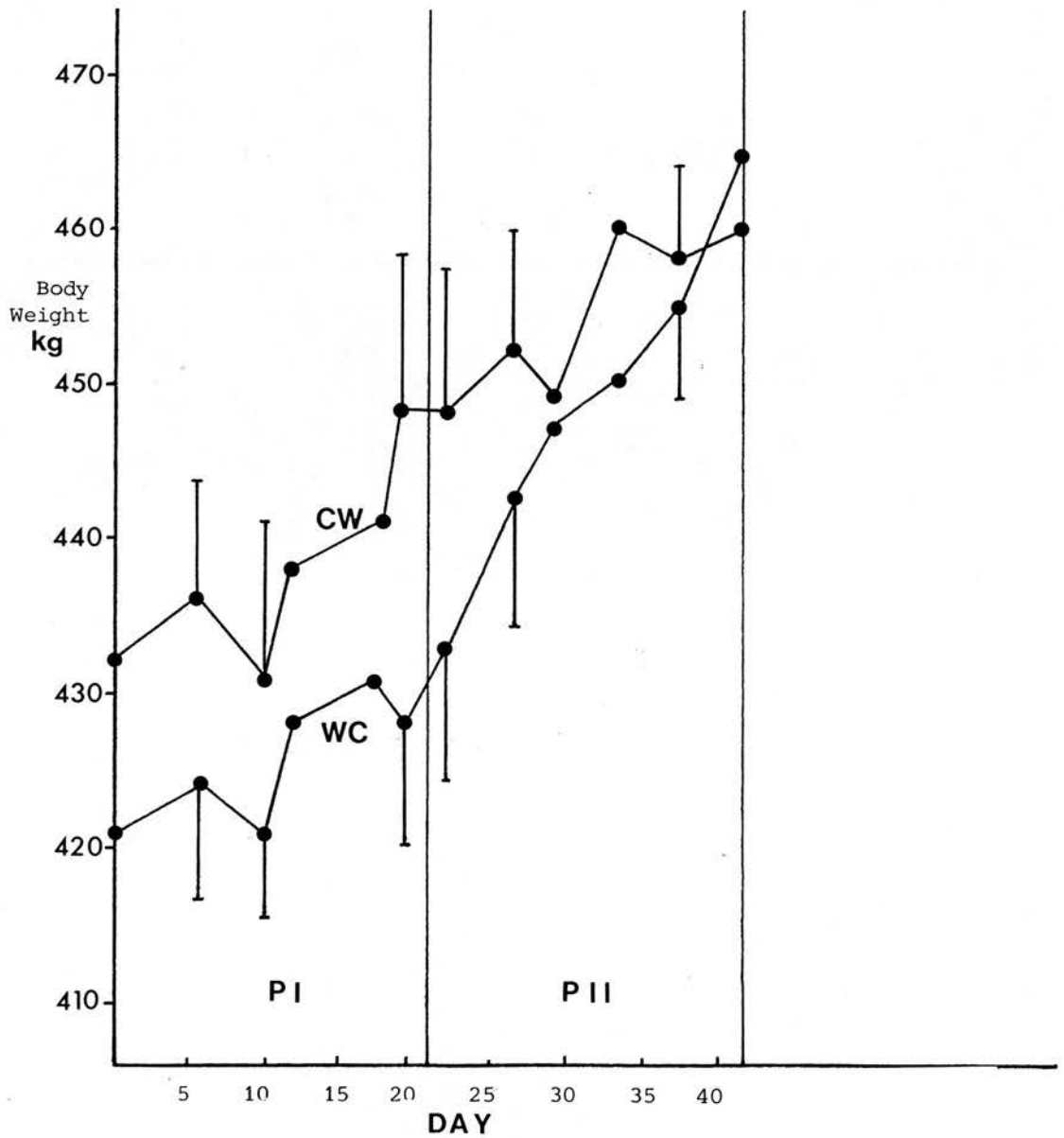
5.4.1. EXPERIMENT I

In Experiment I in which all cows were offered the same high roughage (0.30 barley straw) diet (AA6) to requirement and which had a crossover design with two periods, the weights of all cows increased in both periods, although the cows gained weight more slowly when walking than when resting (Fig 5.28).

The mean weights of cows during non-walking and walking periods were 443.8kg and 440.5kg respectively (Table 5.31). The treatment groups were balanced for body weight at the beginning of the experiment. The cows in one group however, were on average 10kg heavier (431kg) than the cows in the other group (421kg) (Appendix 2B).

The mean non-walking weight gain of animals was 25kg over a 21 day period, compared with a mean walking weight gain of 11kg. This difference was significant ($p<0.01$). In period one the mean non-walking weight gain was 15kg over the 21 day period, whereas

Figure 5.28. Variation in mean body weight (kg) for each treatment group in each period in Experiment I



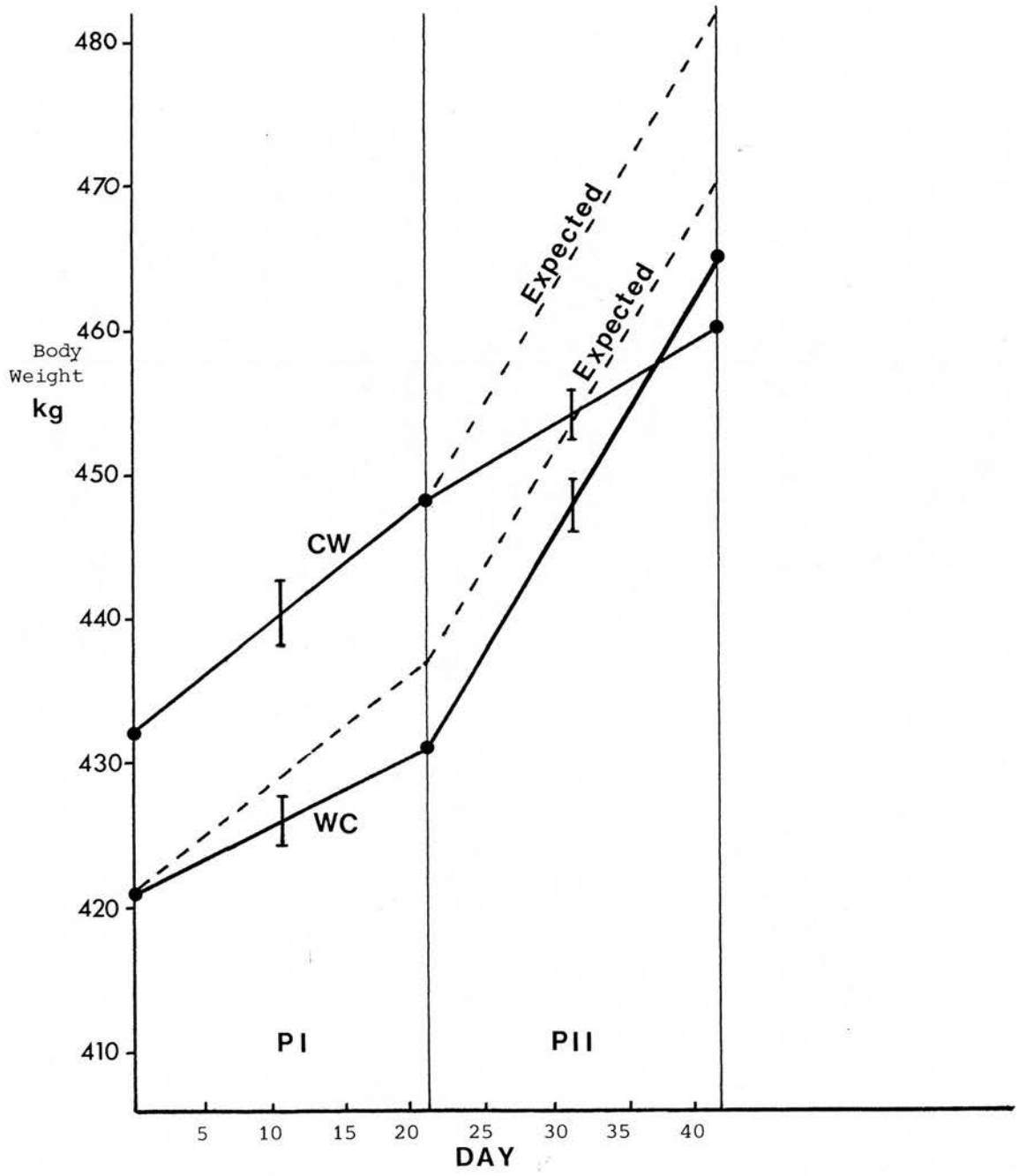
the mean walking weight gain was 10kg. In the second period the mean non-walking weight gain was 35kg compared with a mean weight gain of 11 kg for the walking group in period two.

Table 5.31. Mean Weights (kg) for walking and non-walking groups in each period in Experiment I

TREATMENT	PERIOD	WEIGHT(Kg)
Non-walking	I	438.7
	II	448.8
MEAN		443.8
Walking	I	426.3
	II	454.7
MEAN		440.5
SED (between walking and non-walking means)		1.006 (p<0.01)

These patterns of weight change meant that the weights of the two groups diverged in the first period and converged in the second period. The pattern of weight change is shown more clearly in Figure 5.29. This figure shows the expected weight gains of the walking groups in each period based on the extrapolated weight gains of the non-walking groups in each period. These extrapolations are shown as dotted lines in Figure 5.29.

Figure 5.29. Variation in mean body weight (kg) for each treatment group in each period in Experiment I showing expected mean weight gains based on non-walking group gains



5.4.2. EXPERIMENT II

In Experiment II, which had two dietary treatments (diet AA6, which was also fed in Experiment I, and a high starch diet HS1), the weights of all cows increased in the non-walking periods by an average of 26.7kg, but not in the walking period when mean weight loss was 6kg (Figure 5.30). The difference in weights between non-walking and walking groups was significant ($p<0.001$). Diet did not have a significant effect on weight in this experiment and there was no significant diet/exercise interaction.

The mean weight of cows in Periods I, II and III were 521.3, 528.7 and 549.5 kg (Table 5.32). The non-walking mean was 540.1kg and the walking mean was 528.7kg (Table 5.33). This difference was significant ($p<0.001$).

The treatment groups were balanced at the beginning of the experiment for body weights and the mean weights of each treatment group were 516kg and 510kg (Appendix 2B).

The response of the two dietary treatment groups to exercise was similar. The expected weight gains of the two groups are shown in Figure 5.31 by extrapolation from the non-walking weight gains of the first period (dotted lines). Both treatment groups recovered from the weight losses or reduced weight gains of the walking period and appeared to reach a higher than expected weight by the end of the third period of the experiment. Cows fed diet HS1 were on average 6kg lighter at the beginning of the experiment than cows fed diet AA6, and were 3kg

lighter than cows fed diet AA6 by the end of the experiment (Figure 5.30).

Table 5.32. Mean Weights (Kg) by Period and Treatment for Experiment II

	Period I	Period II	Period III
Diet Group			
AA6	523	530	550
HS1	517	528	549
SED	6.82	4.83	4.83
	ns	ns	ns
MEAN	520.0	529.0	549.5

Table 5.33. Mean Weights (Kg) for Walking and Non-Walking Groups for Experiment II

Group	Not-Walking	Walking	SED
AA6	541.4a	529.6b	4.41
HS1	538.8a	527.7b	4.41
SED	3.94	4.83	
n	36	24	
TOTAL	540.1c	528.7d	3.12

ab = $p<0.05$; cd = $p<0.001$

Figure 5.30. Variation in mean body weights (kg) for each treatment group in each period in Experiment II

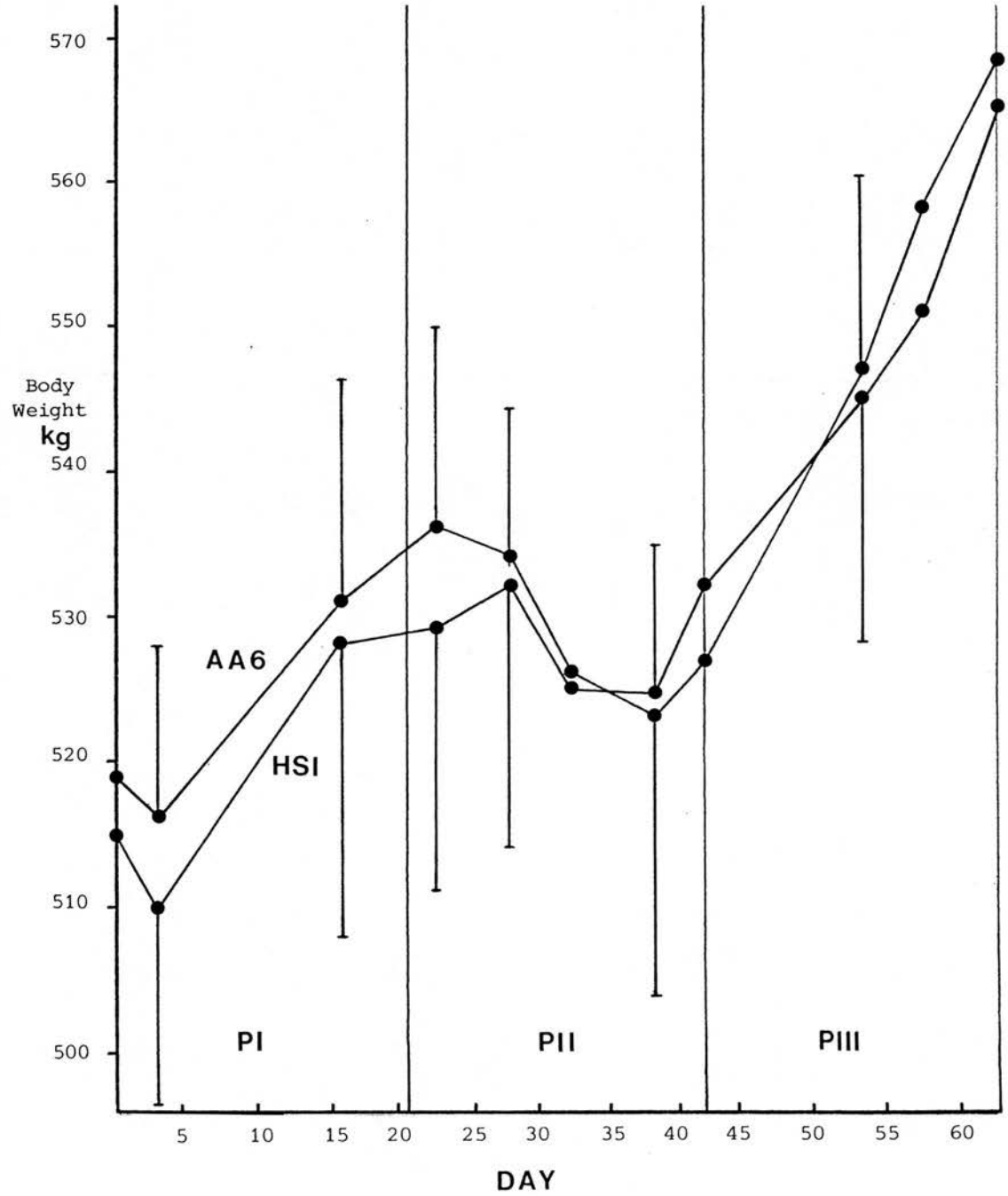
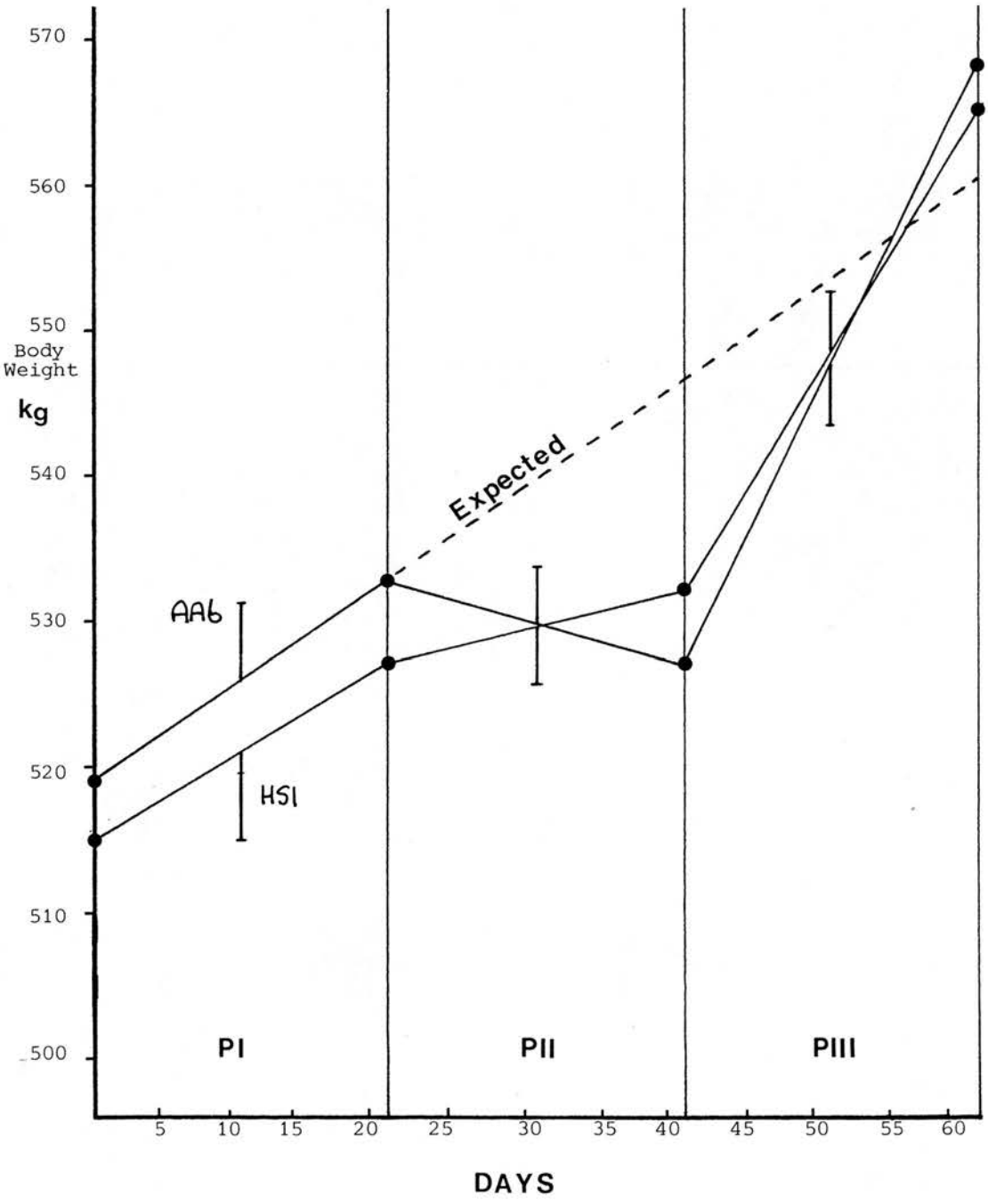


Figure 5.31. Variation in mean body weight (kg) for each treatment group in Experiment II showing expected mean weight gains based on non-walking group gains



5.4.3. EXPERIMENT III

As in previous experiments, the treatment groups were balanced at the begining of the experiment for body weight (Appendix 2B) and the mean weights of each treatment group were similar (501kg, HS1; 506kg, DF; 504kg, HP).

Exercise had a significant ($p<0.05$) effect of body weight. The mean walking and non-walking weights were 500.4 and 504.9kg (Table 5.34).

Diet also had a significant effect on body weight. The mean weights of cows fed on diets HS2, DF and HP were 496.9, 491.2 and 523.2kg respectively. Cows fed diet HP were significantly heavier ($p<0.001$) than cows fed diets HS2 and DF (Table 5.34). The weights of cows fed diets HS2 and DF were not significantly different. There was no diet/exercise interaction.

Whereas in Experiments I and II all cows gained weight in both non-walking periods, in Experiment III some cows on diets HS2 and DF did not gain weight in the first non-walking period. On diet HP all cows gained weight in both control periods. On diets HS2 and DF all cows gained weight in the second control period (Figure 5.32). In the first control period on diet HS2 one cow maintained its weight and one cow lost weight and on diet DF three cows lost weight.

The mean weight increases for non-walking periods 1 and 2 were +12kg and +17kg (HS2), 0kg and +19kg (DF) and +24kg and +33kg (HP) respectively. All diet groups lost weight when they walked; mean losses were -10kg (HS2), -5kg (DF) and -4kg (HP).

Figure 5.32. Variation in mean weights (kg) for each treatment in each period in Experiment III

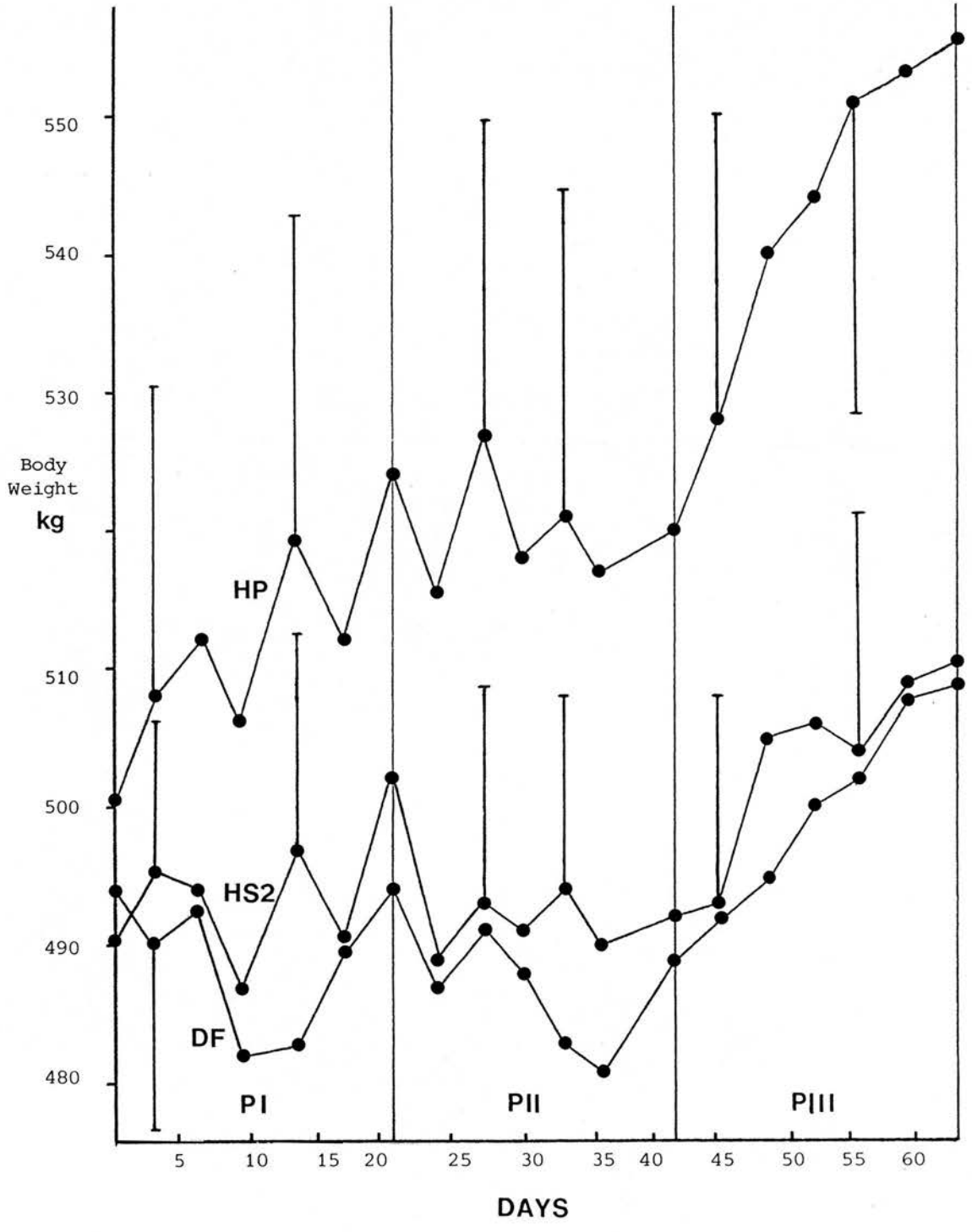


Table 5.34. Mean Weights (Kg) for non-walking and walking groups for each diet in Experiment III

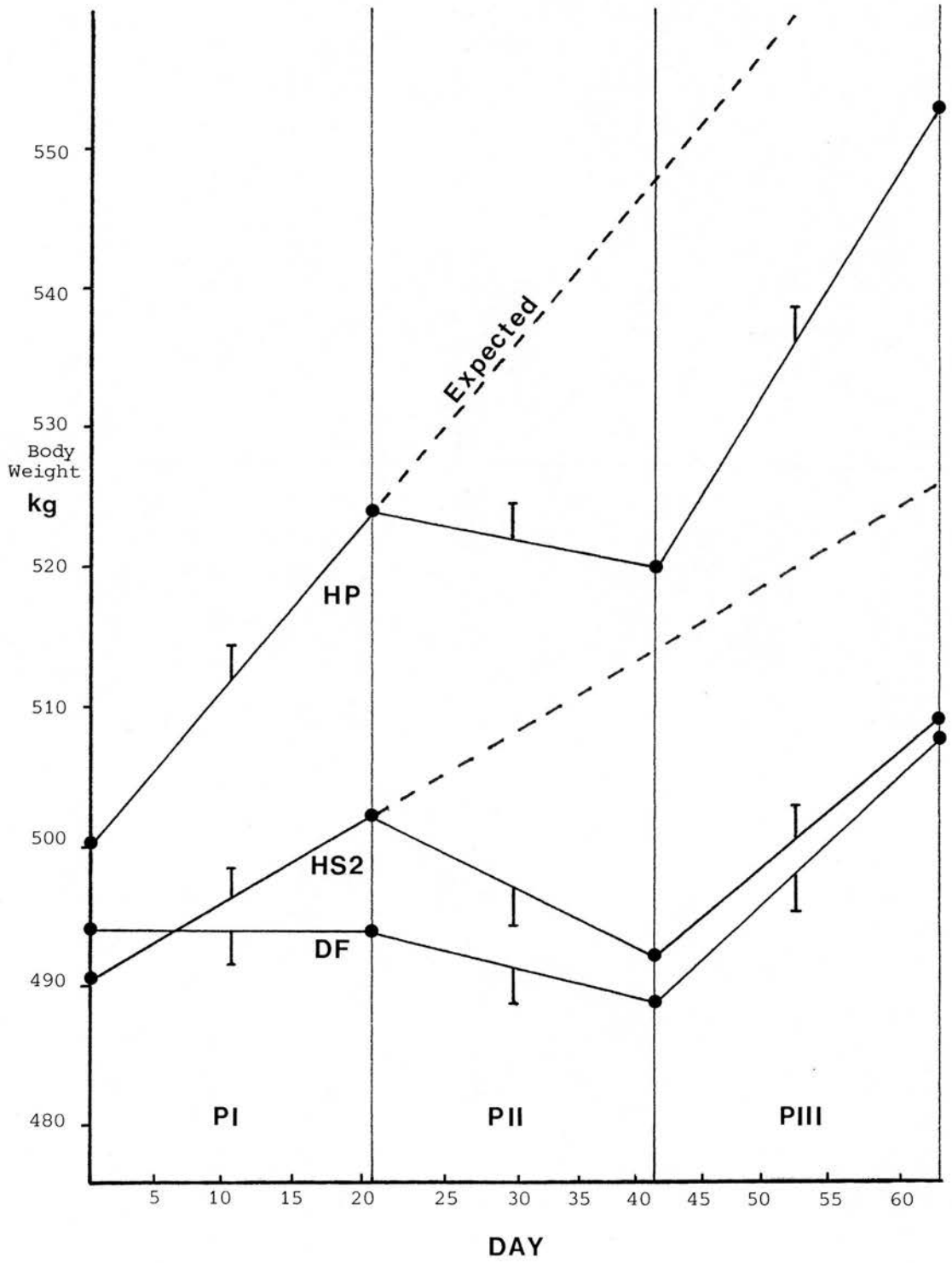
DIET	NON-WALKING	WALKING	TOTAL	SED
HS2	497.12a	493.37a	495.88	3.22
DF	493.12a	487.33a	491.19	3.22
HP	524.44b	520.58b	523.15	3.22
SED	2.63	2.14		
MEAN	504.90	500.43		1.86 ($p<0.05$)

aa = ns; ab = $p<0.001$.

The mean overall control weight gain was 17.1kg compared with a zero weight gain in the walking period. This difference was significant ($p<0.001$). Diet also had an effect on weight gain. In the walking period there was no effect, but in the control periods HP cows gained weight significantly faster than HS2 or DF cows ($p<0.05$). As a result of this, the cows fed diet HP were significantly heavier ($p<0.001$) at the end of the experiment than cows of the other dietary treatments.

The marked difference in growth curves for the groups is shown in Figure 5.33. The expected weight gains of the groups are shown in Figure 5.33 as dotted lines, based on extrapolations of the growth of each group in the first non-walking period. Whereas in Experiment II (but not in Experiment I) cows in both treatment groups achieved their expected weight gains at the end of the second non-walking period, in Experiment

Figure 5.33. Variation in mean body weight (kg) for each treatment group in each period in Experiment III showing expected mean weight gains based on non-walking group gains



III only cows on diet treatment DF met their expected weights. These cows however, had the lowest growth rates of any group. Cows in groups HP and HS2 did not meet their expected weights, although the rate of gain of cows in group HP was greater than in the rate of gain in the first non-walking period.

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5.4.4. BODY CONDITION SCORES

In Experiment I condition scores were taken of the animals twice during the experiment and previous scores were available for some animals. The scores are shown in Appendix 6A. The condition scores of only two animals (8228 and 8125) increased over the experimental period. All other animals maintained condition. The animals were in relatively poor condition with usual scores of 1.75.

In Experiment II condition scores were taken in Periods II and III, but the condition scores of Period II were lost. The cattle were in better condition in Experiment II than in Experiment I, with scores of 2.0 or above. (Appendix 6B).

In Experiment III condition scores were taken in each period (Appendix 6C). The scores of animals varied more than in Experiment II, but on average cows were in slightly better condition than in Experiment I and similar to those of Experiment II with scores of 1.75 to 2.5 at the beginning of the experiment. Between Period I and II there no consistent response of body condition score between animals. In Period II five animals maintained their condition compared with Period I, four animals increased their condition and three animals lost condition. In Period three however, there was a more consistent response compared with Period II, when animals either maintained or lost condition. All animals fed diet supplement HS2 lost condition, two animals fed each of supplement DF and HP maintained condition and two lost condition.

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RESULTS:

THE EFFECT OF EXERCISE ON STRAW INTAKE

RESULTS

5.5. STRAW INTAKE

The effect of exercise on the voluntary intake of whole barley straw offered *ad libitum* and supplemented with one of three diets was investigated in Experiment III.

Prior to the experiment the cows had been fed over winter on a mainly silage diet. During the four week adjustment period before the start of Period I of the experiment the diet was gradually changed from silage to a supplemented straw diet. Feeding methods are described in Section 4.5.1. Mean straw intakes for each cow in each week are shown in Appendix 7.

5.5.1. DATA ANALYSIS

The analyses of variance carried out on the data were the same as described in Section 4.5.3. The data were analysed in three different ways: firstly an analysis of seven day means was carried out; secondly an analysis of walking day means (Monday to Fridays - ie. excluding weekends when the animals did not walk); thirdly an analysis of the walking day means for week three only of each period (ie. to reduce carryover effects between periods). These different analyses were carried out in order to remove as much extraneous variation as possible and to focus the analysis on the treatment effects. Data from non-walking days were excluded because it was observed that cows ate more on the day after walking, which reduced the effect of walking when these data were included in the

calculation of means.

5.5.2. THE EFFECT OF EXERCISE AND DIETARY SUPPLEMENT ON STRAW INTAKE

Exercise and dietary supplement had small, but non-statistically significant, effects on the intake of barley straw (Table 5.35 A, B and C) which are discussed in the following sections.

5.5.2.1. THE EFFECT OF DIET ON STRAW INTAKE

The effect of diet supplement is most apparant from Figure 5.34 which shows the mean weekly straw intakes for each dietary group throughout the nine week period of Experiment III. Cows on diet supplement HP ate slightly more straw than those fed diet supplement HS2, which ate slightly more than those fed diet supplement DF. The difference in means between straw intake of cows fed diet supplements HP and DF however, was not statistically significant. This effect occurred almost immediately after the cows were introduced to their individual supplementary diets after the adjustment phase in which all cows received a mixture of equal proportions of the three supplements. After the first week the mean curves for each diet never crossed again (Figure 5.34).

Over the experimental period straw intake gradually increased from a mean of approximately 4kgDM/d in week one to a mean of approximately 5.4kgDM/d in week nine. This might have been due to an improvement in the quality of straw fed over the experimental period, or to an increased energy demand which could be responded

Table 5.35. Mean straw intakes (kg/d) for animals fed each diet in Experiment III calculated for A. Full Data, B. Walking Days Only and C. Walking Days in Week Three only

A.

	Not-Walking	Walking	SED	Proportional Difference
HS2	4.74a	4.60a	0.20	0.030
DF	4.55a	4.43a	0.20	0.026
HP	5.09a	5.05a	0.20	0.080
SED	0.32	0.36		
Total	4.79a	4.70a	0.12	0.019

B.

	Not-Walking	Walking	SED	Proportional Difference
HS2	4.74a	4.42a	0.25	0.068
DF	4.51a	4.35a	0.25	0.035
HP	5.08a	4.93a	0.25	0.030
SED	0.34	0.40		
Total	4.78a	4.57a	0.14	0.044

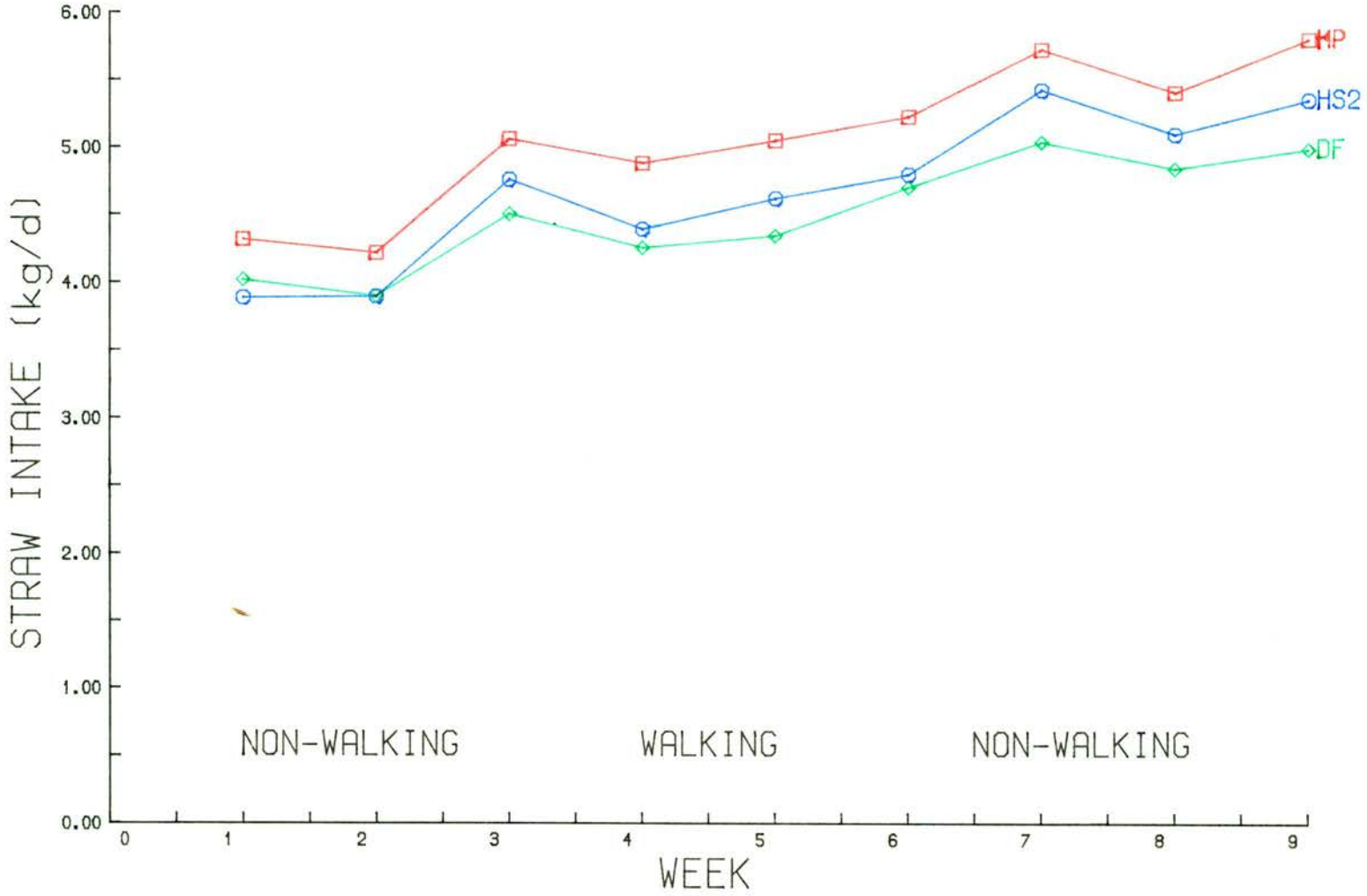
C.

	Not-Walking	Walking	SED	Proportional Difference
HS2	5.17a	4.53a	0.37	0.124
DF	4.78a	4.53a	0.37	0.052
HP	5.55a	5.19a	0.37	0.065
SED	0.38	0.49		
Total	5.17a	4.75a	0.22	0.081

NB. Means with the same subscript in either row or column are not statistically significantly different

SED = Standard Error of the Difference between means

Figure 5.34. Variation in mean straw intake (kg/d) for cows fed diets HS2, DF and HP in Experiment III



to by increasing straw intake, or to a continued slow adaptation to straw after the change from silage. The chemical analysis of straw throughout the experiment is shown in Table 4.7 and shows little change in straw quality over the experimental period. It is unlikely that straw quality had an effect on intake.

Individual animals varied only a little relative to other animals, and all animals responded similarly and in the same relationship to each other throughout the experimental periods. Figures 5.35, 5.36 and 5.37 show the mean weekly intakes for each animal for each diet supplement.

For mean seven day data, diet HS2 resulted in a 0.08 lower intake than for diet HP and diet DF resulted in a 0.02 lower intake than for diet HS2. Analysis of the data for walking days only or for week three of each period made little difference to these proportional differences (Table 5.36).

Table 5.36. Proportional differences between straw intakes for the three diet treatments in Experiment III and for the three analyses carried out

	Mean Straw Intake (kgDM/d)			Proportional Difference between diets	
	HP	HS2	DF	HP/HS2	HS2/DF
Full 7 day data	5.1	4.7	4.6	0.08	0.02
Full walking day data	5.0	4.5	4.6	0.10	0.02
Week 3, walking day data	5.4	5.0	4.7	0.07	0.06

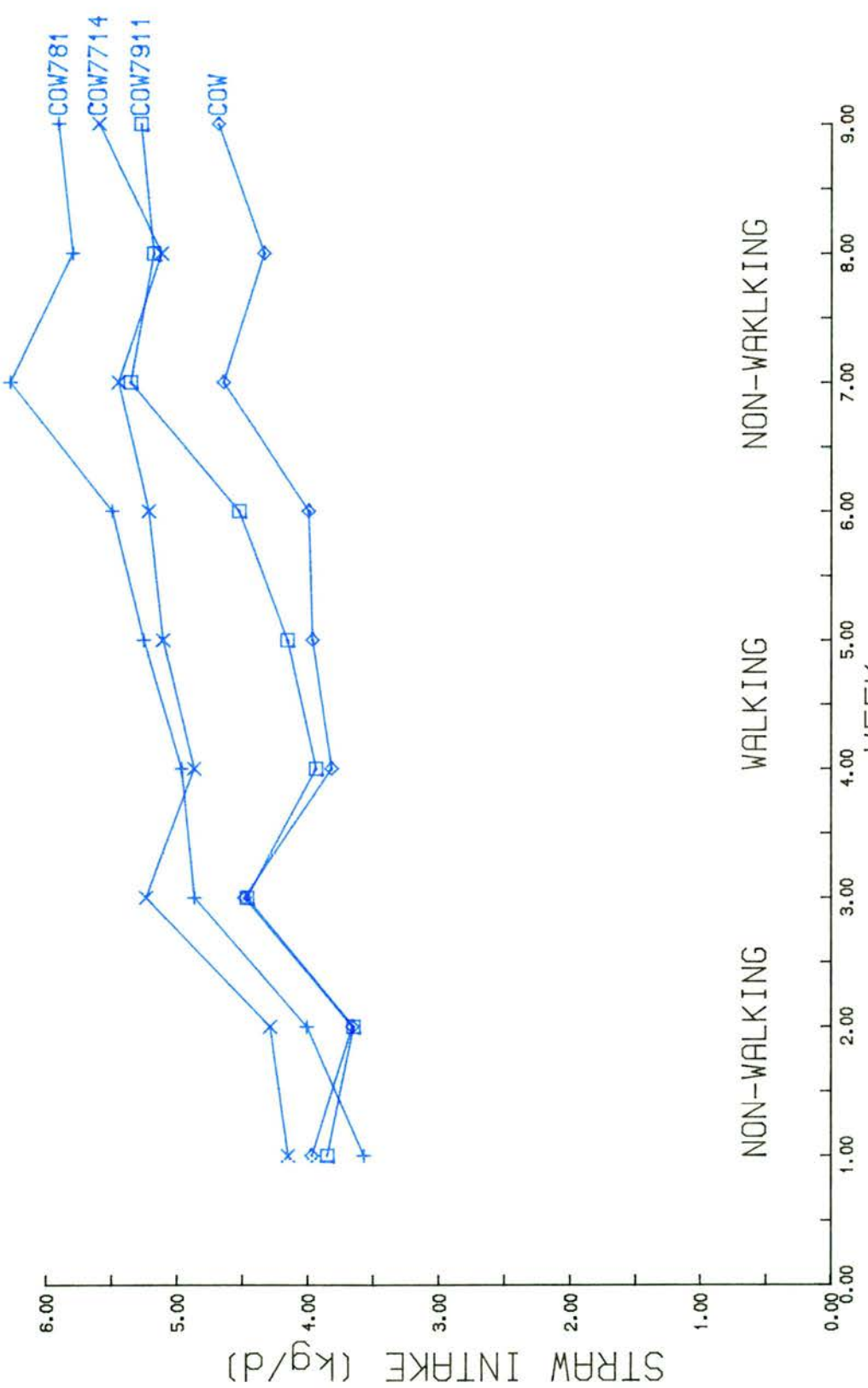
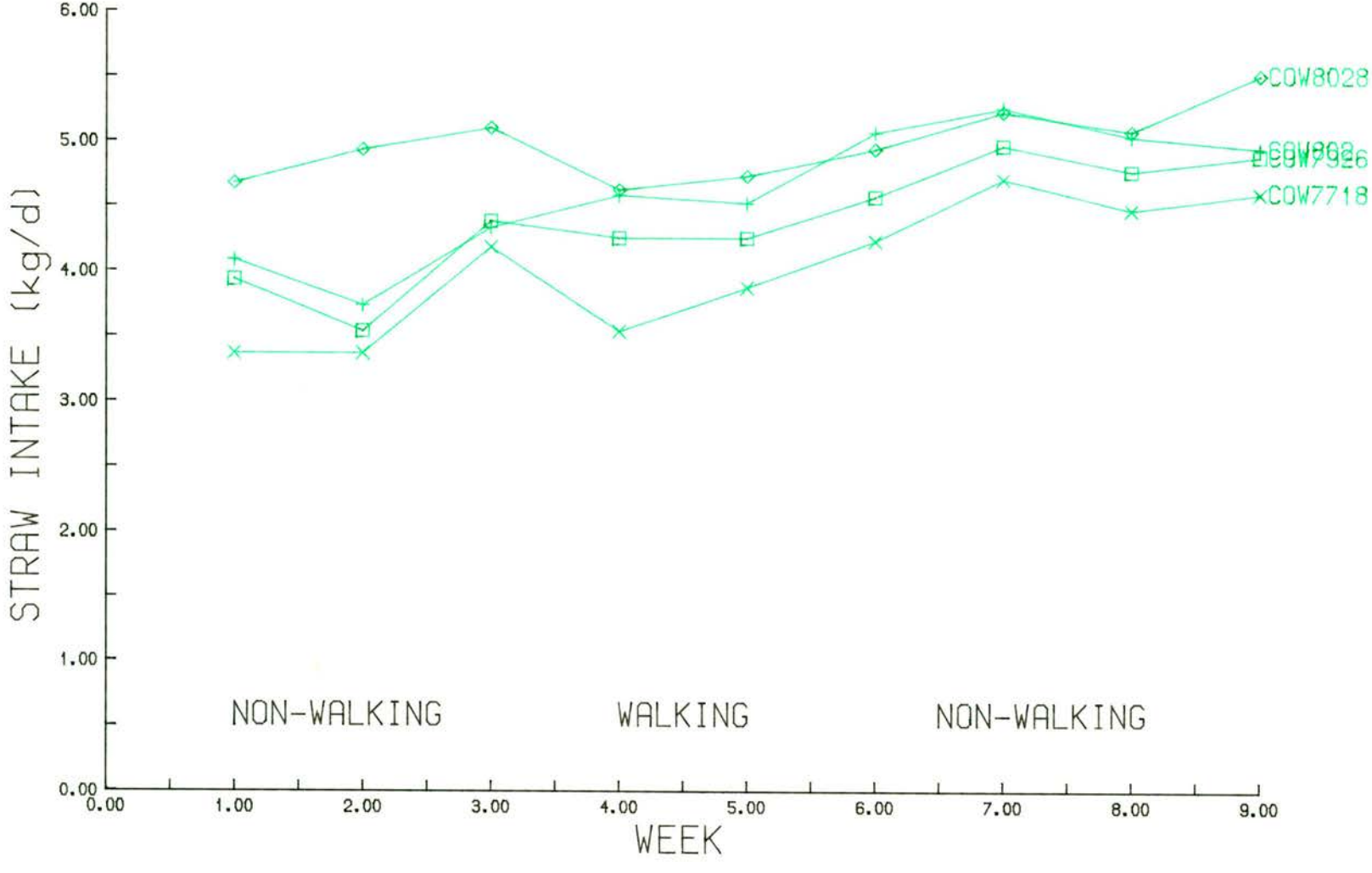


Figure 5.35. Variation in mean straw intake (kg/d) for each cow fed diet HS2 in Experiment III

Figure 5.36. Variation in mean straw intake (kg/d) for each cow fed diet DF in Experiment III



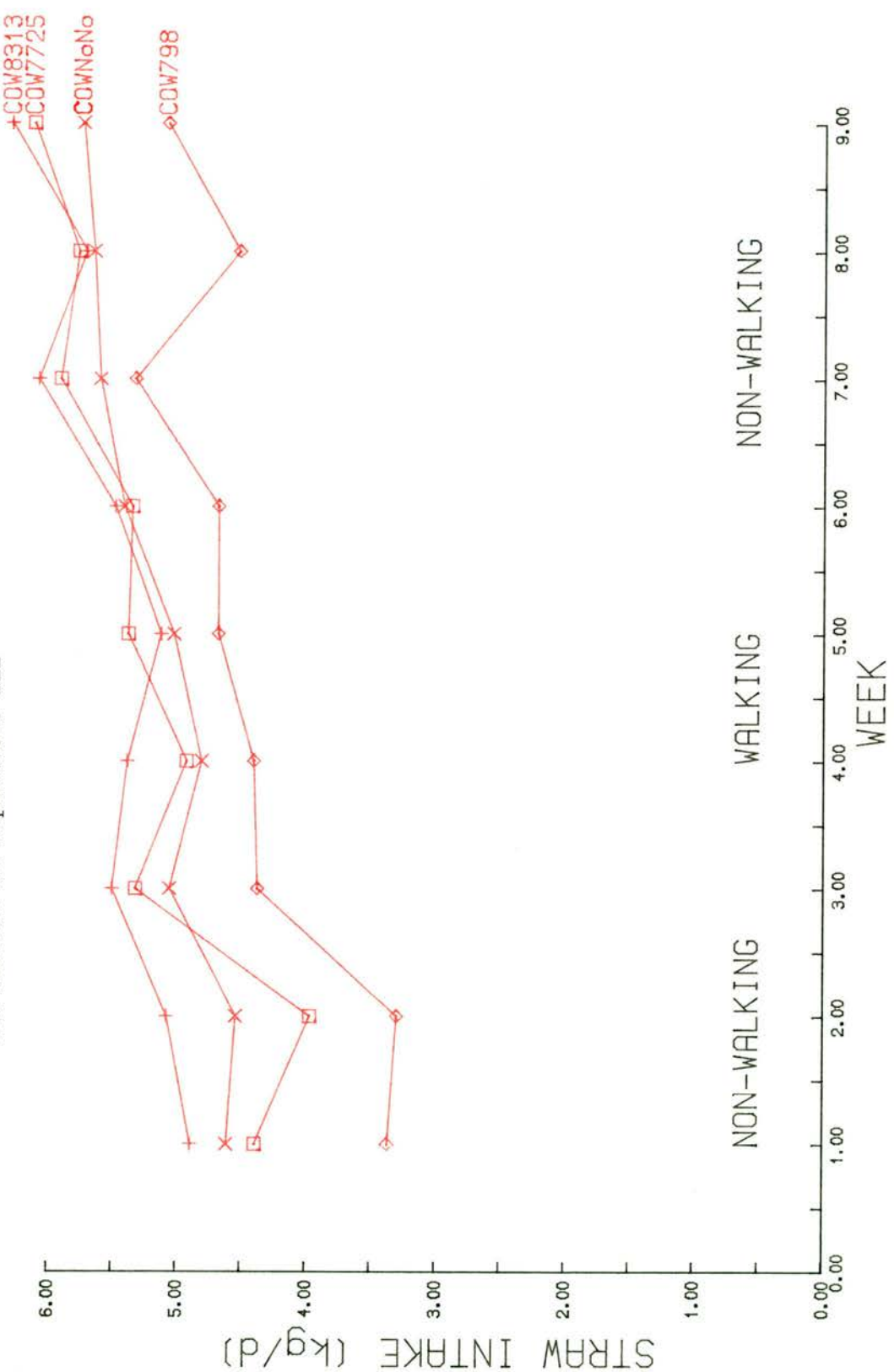


Figure 5.37. Variation in mean straw intake (kg/d) for each cow fed diet HP in Experiment III

5.5.2.2. THE EFFECT OF EXERCISE ON STRAW INTAKE

The effect of exercise on straw intake cannot easily be discerned from Figures 5.34 to 5.37. When animals walked, a reduced food intake was observed for some walking days. This was particularly noticeable during the first walking week and can be seen in Figures 5.38, 5.39 and 5.40 which show the mean daily straw intakes for each day of the experiment for each supplementary diet. Animals walked from Monday to Friday and it was noticeable that on the day(s) following exercise (Saturday/Sunday) animals ate more straw (circled points). A scatter diagram of the three diets is shown in Figure 5.41. The overall effect of walking from the three different analyses was a 0.02 decline (full weekly means), 0.04 (full walking day means) and 0.08 decline (week three/walking day means) in straw intake. Individual diets showed either greater or smaller responses (Table 5.35 A, B and C; proportional differences). The maximum response to exercise was seen in cows fed diet HS2, which had a reduced straw intake of 0.12 in the third walking week. None of these differences were statistically significantly different.

During the experiments the animals spent upto three hours exercising when they ate nothing. No data were collected on time spent eating or the diurnal patterns of eating.

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Figure 5.38. Variation in mean straw intake (kg/d) for cows fed diet HS2 in Experiment III

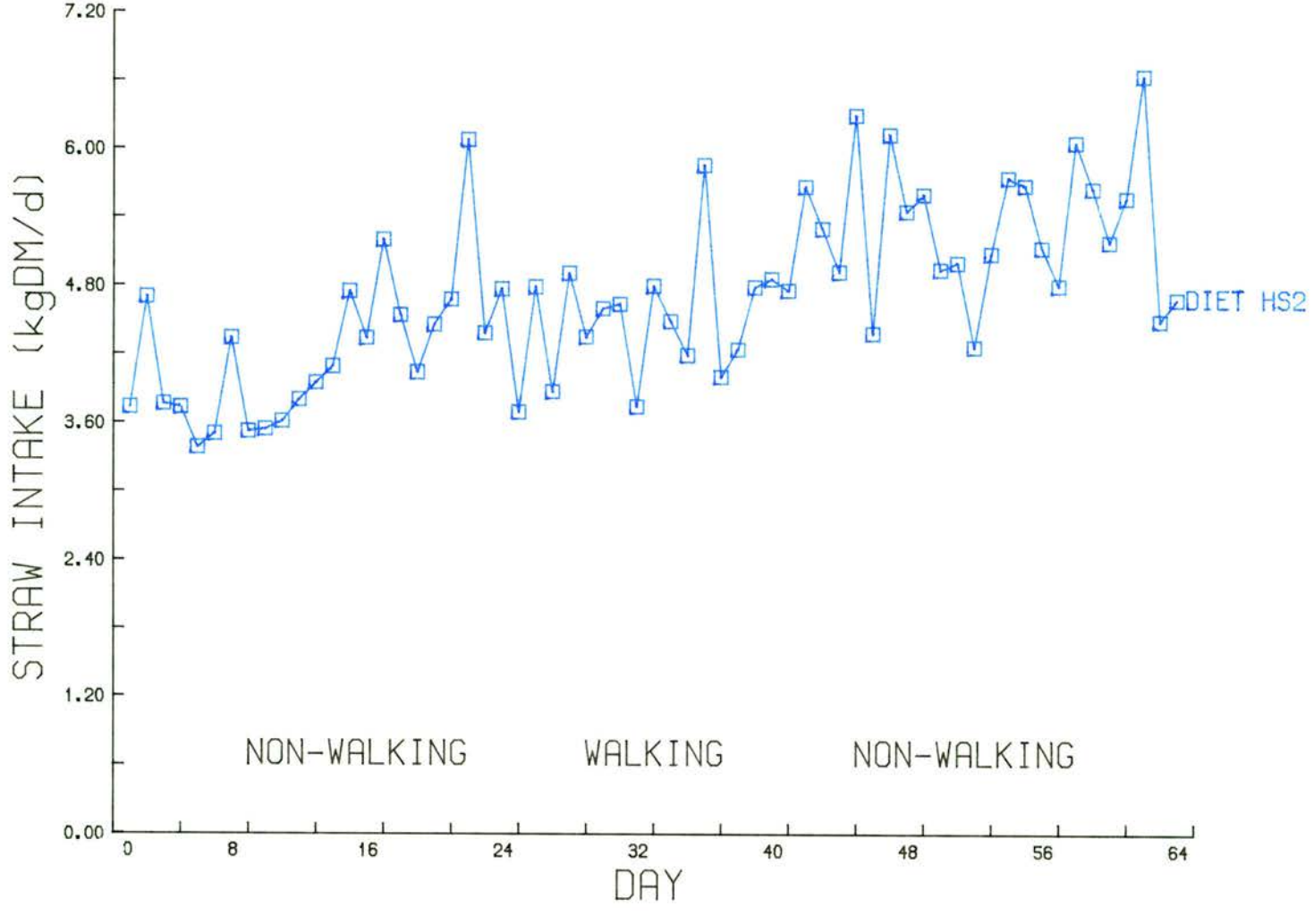


Figure 5.39. Variation in mean straw intake (kg/d) for cows fed diet DF in Experiment III

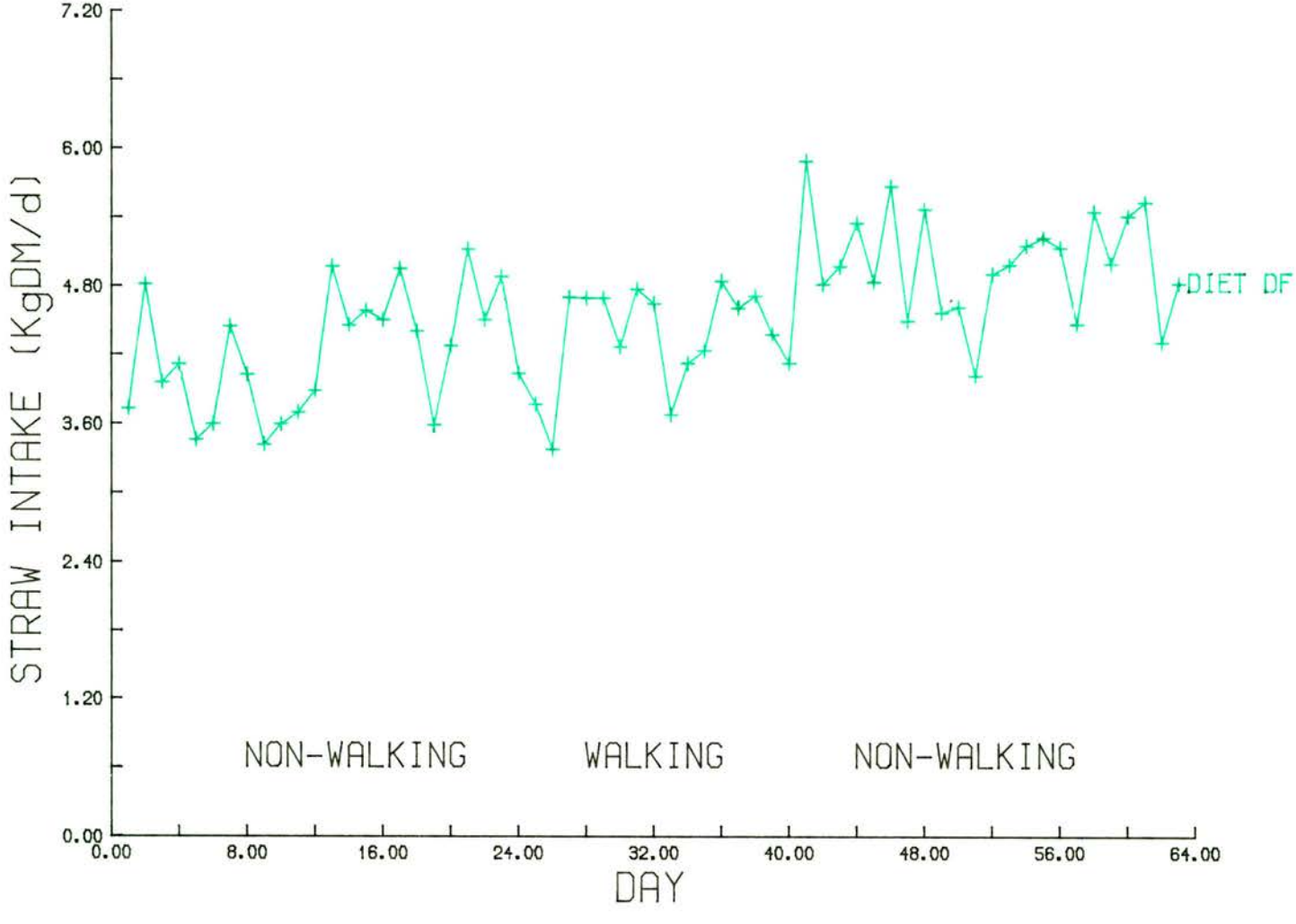


Figure 5.40. Variation in mean straw intake (kg/d) for cows fed diet HP in Experiment III

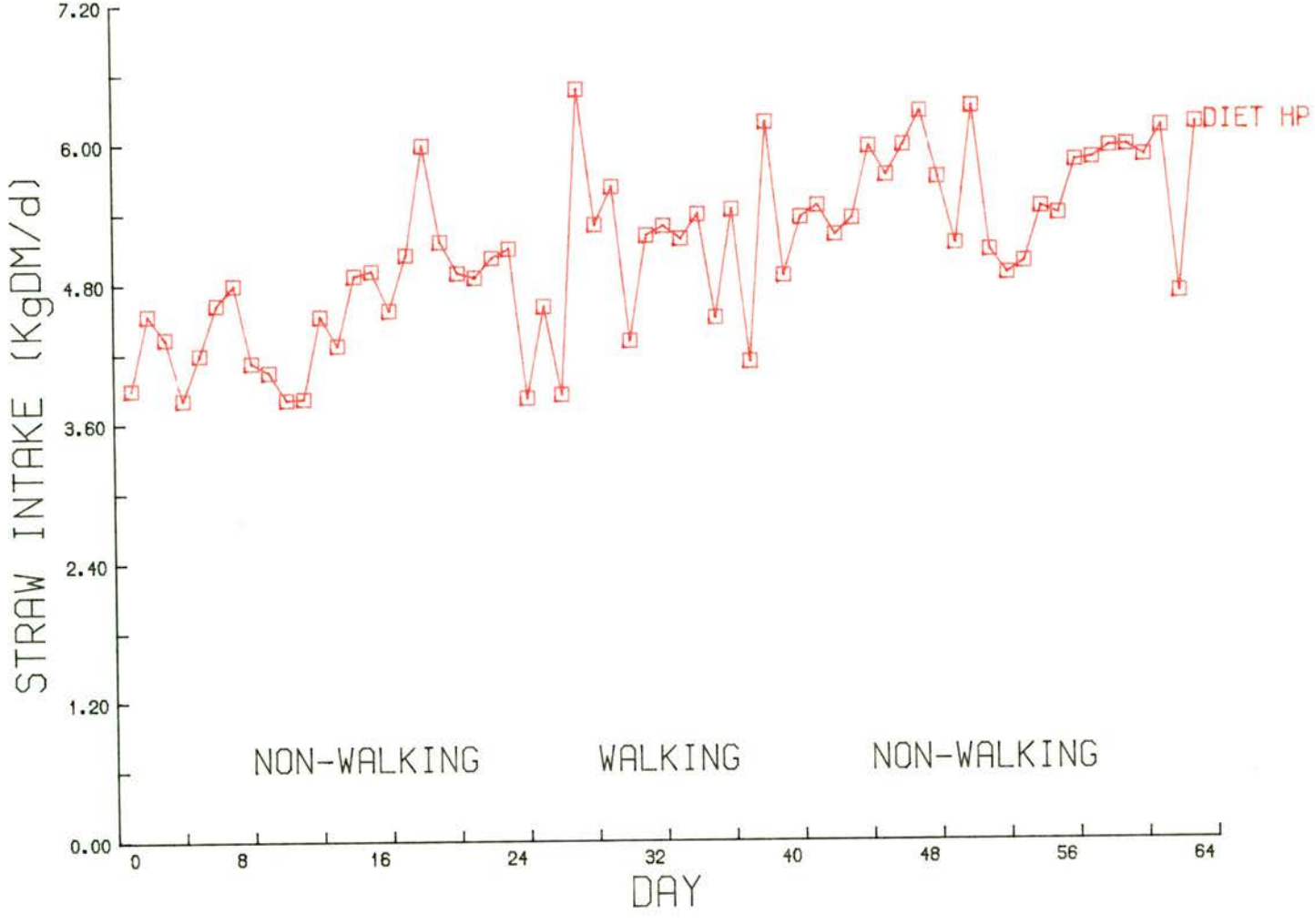
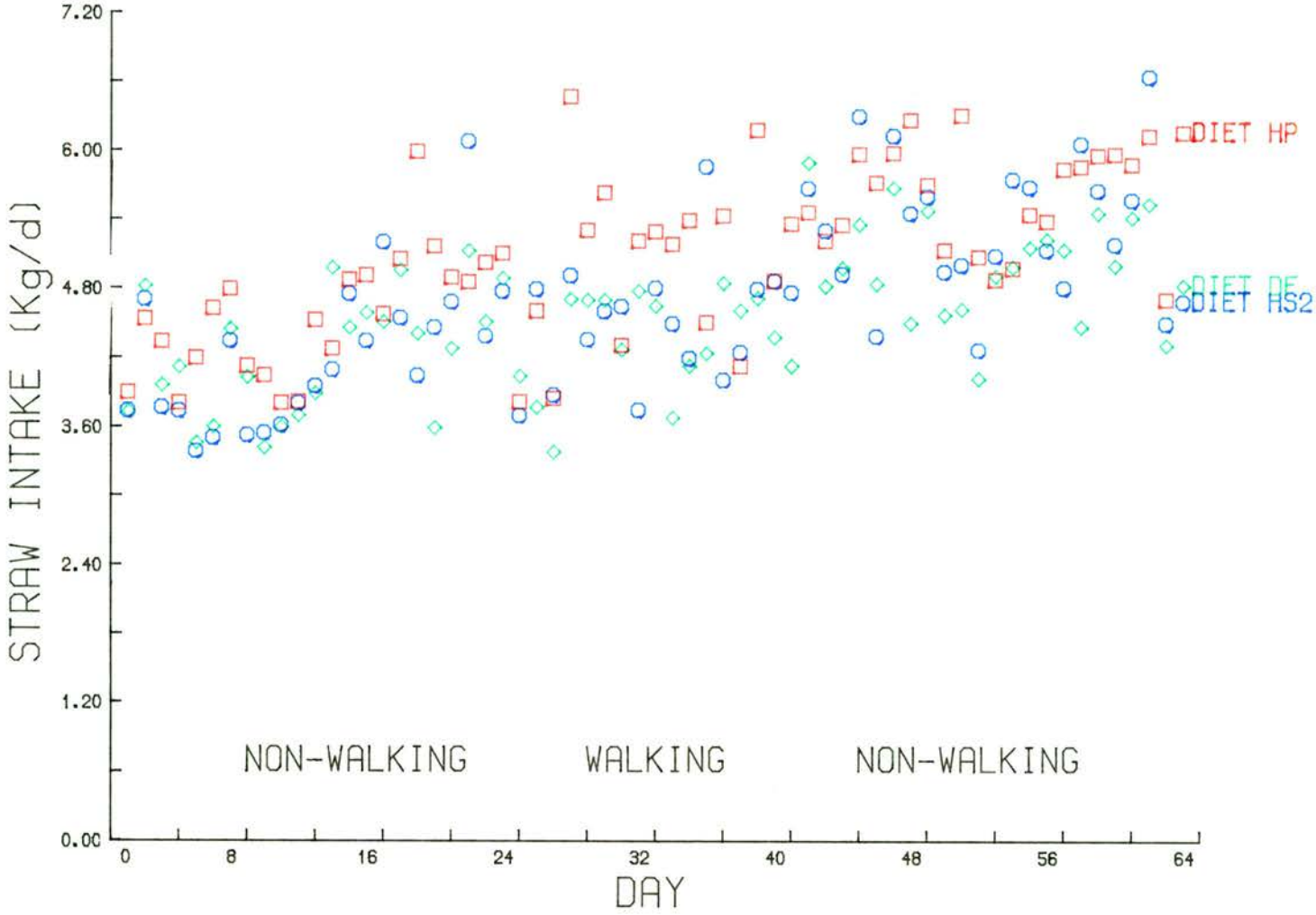


Figure 5.41. Scatter diagram of variation in mean straw intake (kg/d) for cows fed diets HS2, DF and HP in Experiment III



THE PARTITION OF ENERGY FOR EXERCISE AND LACTATION:

A. ENERGY BALANCES

B. ESTIMATION OF METABOLITE SUPPLY AND POTENTIAL MAXIMUM GLUCOSE PRODUCTION FROM EXOGENOUS GLUCOSE PRECURSORS FROM EACH DIET

CHAPTER SIX

THE PARTITION OF ENERGY FOR EXERCISE AND LACTATION

6.1. ENERGY BALANCES

6.1.1. INTRODUCTION

From the mean values for milk yields, milk constituent yields, body weights and body weight changes presented in Chapter Five, calculations of the balance of energy input (from food) and output (for maintenance and production) have been made. In Experiment I energy balances were calculated for each walking and non-walking period and for the two periods combined. In Experiments II and III, energy balances were calculated for each walking and non-walking period for each diet. Energy balances were calculated using the following equation:

$$FOOD_{ME} - (L_{ME} + M_{ME} + C_{ME} + W_{ME}) = \text{ME equivalent of body state change}$$

where L_{ME} = ME for lactation
M_{ME} = ME for maintenance
C_{ME} = ME for the growth of concepta
W_{ME} = ME for walking.

The basic data and assumtions made in order to calculate these energy balances are shown in Appendix 8.

6.1.2. CALCULATION OF ENERGY BALANCES

Energy balances were calculated by the method shown in the example calculation below:

Food ME = 96.1MJ

Energy Value of mean milk constituents synthesised each day:

Butterfat:	233g x 39.3kJ =	9156.9
Protein:	171g x 24.6kJ =	4206.6
Lactose:	348g x 16.0kJ =	5568.0
		18931.5kJ

EV = 18.93MJ
÷ 0.62

Lactation ME	= 30.5MJ/d
Maintenance ME	= 49.3MJ/d
Concepta ME	= 9.2MJ/d (day 198)
Total Expenditure	= 89.0MJ/d

The ME equivalents of body state change for each group in each period in each experiment are shown in Tables 6.1, 6.2 and 6.3. Since each group in Experiments I and II was fed to its requirement for maintenance, lactation and foetal growth, but not for work, it would be expected that walking groups in these experiments would be in energy deficit by the total amount of energy expended for work and that non-walking groups would be in positive energy balance. A slightly different situation might be expected in Experiment III in which animals were given *ad libitum* access (except when walking) to barley straw.

6.1.3. SUMMARY OF RESULTS OF ENERGY BALANCE CALCULATIONS

In Experiment I, the walking animals gained weight less quickly than non-walking animals, and the energy balances shown in Table 6.1. are positive except for walking cows in Period I. The body-weight changes are likely to include some gut-fill changes (see section 5.4).

In Experiment II, in Period II animals fed on diet HS1 were apparently in energy deficit, though showed a negligible increase in body weight. Animals on diet AA6 which were in similar energy deficit to cows fed diet HS1 showed a weight loss of 0.4kg/d.

Table 6.1. Energy Partition (MJ/d) for Experiment I

	Overall Mean		Period I		Period II	
	Non-Walking	Walking	Non-Walking	Walking	Non-Walking	Walking
Food ME	96.1	96.1	99.7	92.5	92.5	99.7
Milk ME	30.5	28.0	35.2	30.0	25.8	25.9
Maintenance ME	49.3	49.1	48.9	47.9	49.8	50.2
Concepta ME	9.2	9.2	8.1	8.1	10.1	10.1
Energy cost of walking (MJ)	0.0	9.2	0.0	8.8	0.0	9.4
Total Cost	89.0	95.5	92.2	94.8	85.7	95.6
Total Energy Balance (MJ/d)	+7.1	+0.6	+7.4	-2.3	+6.8	+4.1
Mean increase in weight (kg)	1.2	0.5	0.8	0.5	1.6	0.6

Table 6.2. Energy partition (MJ/d) for Experiment II

	Period I		Period II		Period III	
	AA6	HS1	AA6	HS1	AA6	HS1
Food ME	110.1	108.4	110.1	108.4	110.1	108.4
Milk ME	44.0	42.9	36.4	35.5	31.2	32.0
Maintenance ME	55.6	55.6	56.1	56.1	58.1	58.1
Concepta ME	7.8	7.8	9.7	9.7	12.1	12.1
Energy Cost of Walking MJ	0.0	0.0	11.0	11.0	0.0	0.0
Total Cost	107.4	106.3	113.2	112.3	101.4	102.2
Total Energy Balance	+2.7	+2.1	-3.1	-3.9	+8.7	+6.2
Mean weight change (kg)	+0.7	+0.6	-0.4	+0.2	+1.6	+1.5

Table 6.3. Energy partition (MJ/d) for Experiment III

	Period I			Period II			Period III		
	HS2	DF	HP	HS2	DF	HP	HS2	DF	HP
Food ME	66.7	60.3	61.3	69.4	61.7	64.1	72.6	64.5	68.2
Milk ME	26.9	21.4	24.8	21.9	13.5	19.3	18.3	7.7	13.4
Maint. ME	53.4	53.0	54.7	53.4	52.9	55.5	54.0	53.7	57.1
Concepta ME	7.8	7.8	7.8	9.7	9.7	9.7	12.1	12.1	12.1
Cost of Walking MJ	-	-	-	12.3	12.1	13.0	-	-	-
Total Energy Cost	88.1	82.2	87.3	97.3	88.2	97.5	84.4	73.5	82.6
Total Energy Balance	-21.4	-21.9	-26.0	-27.9	-26.5	-33.4	-11.8	-9.0	-14.4
Mean weight change (kg)	+0.6	0.0	+1.1	-0.5	-0.2	-0.2	+0.8	+0.9	+1.6

In Experiment III the energy balances were all negative even though in the non-walking periods weight gains were recorded. It is likely that animals were losing body fat and that this was being replaced by protein or concepta. It is possible that even though the animals were in negative energy balance, they could still be gaining weight.

It is likely that although a flat rate value was used for the ME content of barley straw in Experiment III, the straw was used with different efficiency by the animals depending on the dietary supplement.

From each energy balance, the proportional decrease in the energy equivalent of milk which resulted from the reduced milk yield when animals walked can be calculated. The decrease in milk

yield is shown in Table 6.4. (see also Table 5.2 in Section 5.1). Table 6.4 shows the energy content of the mean milk yield for walking and non-walking animals and the proportional difference between these energy contents. The proportional decrease in the energy content of the milk was smaller than the proportional decrease in milk yield for each diet.

The smaller impact of exercise on the ME equivalent of milk than on milk yield can be explained by the differential effect that exercise had on milk constituent yields. Since milk fat yields were affected less by exercise than lactose and milk protein yields (Section 5.2), the energy content of the milk remained higher than might be expected. Exercise had a smaller effect on the overall energy content of milk than would have been predicted from a knowledge of the effect of exercise on milk yield.

Table 6.4 The energy content (MJ) of the mean milk yields for non-walking and walking animals for each diet and each experiment and the proportional difference between these

Experiment	Diet	ME Equivalent of Milk Yield (MJ) Non-Walking	Walking	Prop. Decrease	Comparative Decrease in Milk Yield
I	AA6	30.5	28.0	0.08	0.10
II	AA6	37.6	36.4	0.03	0.10
	HS1	37.5	35.5	0.05	0.08
III	HS2	22.6	21.9	0.03	0.08
	DF	14.6	13.5	0.08	0.09
	HP	19.1	19.3	(+0.01)	0.13

The difference in response between the two AA6 diets is difficult to explain other than by reference to the possible milk sampling error in Experiment I which arose from poor mixing of the milk before taking the sample in the first week of the experiment (see Section 4.2.7.2.). The result for AA6 in Experiment II is likely to be more reliable in this respect than for Experiment I.

The differences between the response of the ME equivalent of milk and the actual milk yield response can be explained by the change in milk fat yields resulting from each diet. The smaller difference between the ME equivalent of milk yield response and the milk yield response for diets HS1, HS2 and DF can be explained by the relatively large decrease in milk fat yield resulting from these diets (see Table 5.14). Similarly, the greater difference between the response of the ME equivalent of milk and milk yield resulting from diets AA6 and HP can be explained by the relatively small change in milk fat yield resulting from these diets.

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6.2. ESTIMATION OF METABOLITE SUPPLY FROM EACH DIET IN EACH EXPERIMENT

6.2.1. INTRODUCTION

The nutrient content of diets in the present experiments were varied by changing the roughage to concentrate ratio and the quantities and qualities of the roughage and concentrate offered. The factors which affect the supply of metabolites from each diet include the following:

- the type of rumen fermentation (which determines the quantities and proportions of volatile fatty acids produced in the rumen)
- the ratio of digestion in the rumen to digestion in the whole digestive tract (DOM_R: DOM_T)
- the supply of nutrients to the small intestine
- the characteristics of post-ruminal digestion and absorption.

A brief discussion of how these factors might influence metabolite supply in the present diets is given in the following sections. No direct estimates or measurements of metabolite production were made in the present experiments, but estimations have been made by other authors (eg. Sutton, 1985; Ortigues, 1987). Examples of these estimations are given and indicate the type of metabolite production from the diets in the present experiments.

6.2.2. PRODUCTION OF RUMEN VOLATILE FATTY ACIDS

The quality and ratio of volatile fatty acids (VFAs) is determined by the composition of the food entering the rumen and

the level of feeding. The dietary constituents affect the level of fermentation, the VFA ratio and the proportion of DOM digested in the rumen relative to the whole tract (DOM_R: DOM_T).

The ratio of VFAs, particularly the ratio of propionic acid to acetic/butyric acids is an important determinant of both milk yield and composition (Oldham, 1985). Published rates of net production for VFAs cover a wide range from about 1.5 to 8.3 mol/kg digestible dry matter (DDM) for acetic acid and from 0.8 to 3.8 mol/kg DDM for propionic acid (Sutton, 1985).

The diets used in the present experiments varied in roughage content from 0.17 to 0.56. Diet AA6 had 0.30 chopped barley straw, whereas diet HS1 had 0.17 chopped barley straw. In Experiment III whole barley straw was fed *ad libitum* to all cows and represented up to 0.56 of intake (fresh weight). Table 6.5. summarises the roughage content of the diets in each experiemnt.

Since rumen acetate production is higher on roughage diets, it would be expected that the diets in Experiment III (HS2, DF and HP) would produce higher acetate and lower propionate levels than diets HS1 and AA6. It would be expected that diet HS1 would produce the lowest acetate levels. High acetate levels promote milk fat synthesis (Vernon, 1981), but higher milk yields are favoured by diets which promote higher proportions of propionate in the rumen (Sutton, 1980).

Cows which received diet HS1 performed slightly better than cows on other diets in terms of lactational performance when animals walked (Section 5.1 and 5.2). This can be explained partly in terms of the low roughage content of the diet, which would

Table 6.5. The proportions of roughage and concentrate in each diet in each experiment (Wet weight)

Diet	Roughage (Barley Straw)	Concentrate[1]
AA6	0.30	0.70
HS1	0.17	0.83
HS2	0.54	0.46
DF	0.53	0.47
HP	0.56	0.44

1. Includes all other componants

promote high propionate and low acetate production. Based on anticipated levels of rumen acetate production, relative milk fat content levels (low, medium and high) can be predicted for each diet. Such predictions are shown in Table 6.6. Diets HS2 and DF did not conform to this prediction (Section 5.2.1) and the milk fat contents which resulted from these diets were lower than for diet AA6 (Table 5.13).

Diet HS1, which was predicted to produce low rumen acetate levels and low milk fat contents, produced the lowest milk fat levels of any diet in non-walking and walking periods (Table 6.6). Diet HP had predictably high levels of milk fat, but diets HS2 and DF which had similar proportions of roughage produced lower milk fat contents.

A higher level of acetate production on higher roughage diets and a lower level on low roughage diets would explain the levels of milk fat production and the responses of milk fat yield to exercise

in cows on diets AA6, HS1 and HP.

Table 6.6. Predicted and actual levels of milk fat content for each diet in each experiment

	Milk Fat Content		
	Predicted	Actual (g/kg) Non-walking	Walking
AA6 (Ex I)	Medium	39.5	43.4
AA6 (Ex II)	Medium	39.6	45.4
HS1	Low	32.8	34.0
HS2 (Ex III)	High	35.3	40.0
DF	High	35.1	42.4
HP	High	39.7	48.8

When animals walked, milk fat yields (g/d) increased on the high roughage diets in Experiment III and on diet AA6 in Experiment II. Fat yields declined on the barley/low roughage diet (HS1).

The quantity and type of volatile fatty acids produced, can also be influenced by the proportion of digestion in the rumen (Sutton, 1980). The contribution of the rumen to total organic matter digestion decreases as the proportion of forage in the diet decreases and depending on the type of concentrate fed. Hence, Sutton (1985) described how the replacement of rolled barley with ground maize reduced the ratio of organic matter digested in the rumen to organic matter digested in the whole tract (DOM_R: DOM_T) from 0.75 to 0.70 for 40% roughage diets and from 0.73 to 0.63 for 10% roughage diets in Friesians fed at three times maintenance.

Sutton (1985) concluded that for diets consisting of 40% forage with concentrates based on barley and maize, rumen VFAs contribute 52% and 48% of total digestible energy (DE_T) respectively. For diets containing 10 - 15% forage, rumen VFAs contribute 55% and 47% of DE_T respectively for barley and maize. On this basis in the present experiments, on diet HS1 (17% roughage and 45% barley) rumen VFA can be assumed to have contributed approximately 55% of DE_T, on diet AA6 (30% forage and 23% barley) rumen VFA may have contributed nearer 52% and on diet HS2 (54% forage and 40% maize) rumen VFA can be assumed to have contributed 48% of DE_T. This would represent a stepwise reduction in propionate production for each of these diets.

6.2.3. LEVEL OF DUODENAL STARCH DIGESTION

The type of diet ingredients also determine the proportion of dietary substrates which pass through the rumen to be digested in the small and large intestines (mainly starch and amino acids, but also fibre).

Ground maize is less digestible in the rumen of lactating cows than barley or wheat (Sutton, Oldham and Hart, 1980). Duodenal starch comprised 0.11 of starch consumed on barley diets and 0.28 of starch consumed on maize diets (Sutton and Oldham unpublished, quoted by Sutton, 1985). The effect of including barley in a diet would be to increase the yields of the products of rumen fermentation, whereas including ground maize would increase the yield of duodenal starch at the expense of rumen products. Sutton (1985) concluded that the inclusion of barley would increase milk

yield, but that maize would not. He attributed this to differences in the metabolism of propionate and of duodenally absorbed glucose and surmised that milk yield is stimulated more by propionate than by exogenous glucose. This may be related to the effect that exogenous glucose would have on insulin release which would inhibit milk production. The source of glucose (exogenous compared with endogenous) may play a part in this control.

It would be expected that diets AA6, HS1, DF and HP would result in approximately 0.10 of their starch being digested in the small intestine. For diet HS2 which was based on maize rather than barley, approximately 0.28 of the starch might be digested in the small intestine.

Factors which alter the balance of digestion in favour of post-ruminal digestion will reduce the quantities and ratio of VFAs produced in the rumen (particularly propionate), except at high levels of production. It follows that at lower levels of feed intake, diets which encourage digestion in the small intestine should only be advocated once optimum rumen digestion has been achieved.

6.2.4. PROTEIN DEGRADATION

The high protein diet in the present experiments might be expected to increase rumen digestion as a result of more efficient synthesis of microbial protein, but Tamminga, van der Koelen and van Vuuren (1979) demonstrated that as dietary protein content increases, although this can cause an increase in the amount of N entering the duodenum, in their experiments this was not accounted

for by an increased efficiency of microbial synthesis (g microbial nitrogen synthesised/100g carbohydrate apparantly fermented in the rumen). This is contrary to what would be expected at lower levels of intake and on poor quality diets, but the effect was confirmed by Ortigues (1987) who demonstrated a greater supply of protein to the duodenum on high protein diets, but with no significant effect on rumen fermentation.

In Experiment III in the present experiments, the high protein diet produced the highest intake of straw. This suggests that the diet increased the rate of rumen fermentation, which increased the rate of passage and DMI. This can be explained by the effect of RDP on rumen fermentation, since a positive relationship has been shown to exist between rumen degradable protein (RDP) intake and VFI of straw and ME obtained from straw (Alawa, Fishwick, Parkins and Hemingway, 1987).

A full discussion of the protein-energy relationships for lactating cattle has been presented by Oldham and Smith (1982). The general model of protein-energy relationships described by these authors suggests that the milk output response to increments of protein is linear up to the animal's genetic potential, assuming that no other nutrients are limiting. Where energy input is limiting, responses to increments of protein decrease. In this process, part of the increment is oxidised to provide the energy which allows the remainder to be used. The point can then be reached at which the energy cost of handling the end products (amino groups) of oxidation, more than outweighs the advantages of high protein supply. In this case a negative response might be

expected.

Increased rumen N supply (ie. RDP) on the high protein diet in the present experiments may be indicated by the observed high blood urea levels (see Figure 5.22) which may have resulted from rumen breakdown of protein and increased ammonia production. The high protein diet produced high blood urea levels throughout the experimental period and these did not return to original levels, but remained high in the non-walking period after exercise had finished. This would appear to be clear evidence of the effects described above (Oldham and Smith, 1982) and suggests that the high fishmeal diet was over-supplying protein. What is surprising is that even at low yield levels the protein supplied in excess of requirements did not appear to be used to provide glucose to meet the deficit from walking or the glucose required for lactogenesis. High blood urea levels can also indicate protein catabolism (Bruckental, Oldham and Sutton, 1980) and high blood urea levels in the present experiments may indicate high levels of protein catabolism.

In the present experiments the high protein diet did not sustain milk yield as well as the high starch (maize) diet HS2 and produced a 0.14 lower milk yield than diet HS2. When animals walked, the milk yield of animals on the high protein diet declined slightly more than the yields of cows on diet HS2. This suggests that the HP diet was also not able to supply the extra energy needs for walking, and that the excess protein was not used for glucogenesis.

The lower milk yield which resulted from diet HP compared with

diet HS2 in Experiment III could be explained by a combination of factors:

- a reduced propionate: acetate ratio resulting from increased straw intake
- replacement of fermentable substrates in diet HS2 by a partially undegradable protein fraction (fish-meal and soya-bean meal).

Ortigues (1987) compared fish meal and barley supplements to a basal diet of rolled barley and barley straw and found that the enriched barley diet produced the greatest quantities of both acetate and propionate. The inclusion of fish meal increased the supply of amino acids and glucose precursors to the duodenum and the growth of heifers in these experiments. The benefit in this case of the increased amino acid supply to the duodenum was to meet the demand for growth, not for glucogenesis. Both Sutton (1985) and Ortigues (1987) found propionate to be produced at highest levels on enriched barley diets.

Miller (1973) noted that an increased rate of passage would have the effect of further reducing the protein degradability. This may have occurred in animals on the high protein diet (HP) in the present experiments.

It is now considered that at high levels of feed intake, amino acids supply only small quantities of glucose from glucogenesis. This infers that the supply of amino acids from undegradable protein is used mainly to supply the needs for amino acids for lactation and not for glucogenesis. If this is the case, glucose to support high levels of production must be found from other sources.

At high levels of production amino acid supply appears to be an equally important controller of milk yield as glucose supply. Evidence for these conclusions however, has been gained from studies of high producing dairy cows, at high levels of food intake and which have not been subjected to undue exercise or work.

The evidence suggests that high milk yield is supported best on diets which produce high levels of rumen fermentation and which result in high levels of propionate production. In the present context, barley diets achieve this better than maize diets. At low levels of intake in the present experiments, the inclusion of fish meal in the diet possibly stimulated fermentation and increased DMI, but did not support lactation as well as the high maize diet. The substitution of fish meal for maize and maize for barley appears to suppress milk yield at low levels of intake. It would appear that the supply of propionate is the key limiting factor to milk production in the present experiments, and that the alternative diets used in the present experiments have reduced propionate production and have not been able to compensate for the lower potential to produce glucose. On high roughage diets, supplements which stimulate propionate production are favoured over those which favour digestion in the small intestine. The present experiments did not directly compare barley and maize supplements to high roughage (>50%) diets and such a comparison would be appropriate.

6.2.5. ESTIMATION OF METABOLITE SUPPLY FROM COMPARABLE DIETS TO THOSE USED IN THE PRESENT EXPERIMENTS (SUTTON, 1985; ORTIGUES, 1987)

Sutton (1985) estimated individual products of digestion in the gastroinestinal tract (DE_T) of lactating cows for diets based on barley concentrate with hay to concentrate ratios of 40:60 and 10:90 and on diets based on maize at a hay to concentrate ratio of 40:60 (Table 6.7). Such diets are broadly comparable with diets AA6, HS1 and HS2 respectively in the present experiments.

Table 6.7. Estimation of individual products of digestion in the gastrointestinal tract (DE_T) of lactating cows from three diets (Mcal nutrient/100 Mcal DE_T) (Sutton, 1985)

	Barley		Maize
Hay: concentrate	40:60[1]	10:90[2]	40:60[3]
Digestible energy in the rumen	67	64	62
Acetic	22	15	21
Propionic	13	25	13
Butyric	11	8	10
Higher VFA	6	7	4
Total VFA	52	55	48
Heat plus methane	15	9	14
Small intestine			
Nonammonia N x 6.25	21	21	21
LCFA	5	6	6
Starch to glucose	2	4	4
Starch to VFA	1	2	2
Large intestine			
Starch to VFA	1	1	1
Fibre to VFA	3	2	4
Intestinal VFA	3	4	5

1. Comparable with diet AA6. 2. Comparable with diet HS1
3. Comparable with diet HS2

Similarly, Ortigues (1987) presented estimates of the products of digestion for barley diets supplemented with fish-meal fed to dairy heifers (Table 6.8). These diets are of comparable nature to the high protein diet (HP) used in the present experiments.

The highest levels of propionate production in both Sutton's and Ortigues' calculation occurred on the high barley diets. The high barley diets also produced the greatest total amounts of VFAs in both cases. The high maize diet in Sutton's calculation produced more glucose from duodenally digested starch. The additional fish meal in Ortigues' calculation reduced the total energy available from VFAs, but increased the overall supply of glucogenic substrates. Similar responses would be expected to result from the diets in the present experiments.

Table 6.8a. Estimated energy available in the form of VFA (from the rumen and large intestine), starch, fat and amino acids (from the small intestine) MJ/d (Ortigues, 1987)

	DIET[1]			
	B	BF	Bb	BbF
Acetate	7.26	7.17	9.72	8.18
Propionate	3.06	2.97	4.42	3.36
Butyrate	2.45	2.32	3.49	2.94
Valerate	0.47	0.57	0.81	0.80
Total VFAs	13.24	13.03	18.44	15.28
Starch	0.83	1.43	1.28	1.97
Fat	-0.15	-0.08	1.54	1.70
Amino acids	6.09	7.21	8.32	10.18
Total	-20.01	21.59	29.58	29.13
% VFA	66.17	60.35	62.34	52.45
% Glucose Precursors (Pr + St. + AAs)	49.88	53.77	47.4	53.24

1. Diets: B = 2.14 Kg Ammonia treated straw + 1.09kg rolled barley; BF = B + 0.78kg rolled barley + 0.34kg fishmeal; Bb = B + 2.01 kg rolled barley; BbF = B + 1.55kg rolled barley + 0.46kg fishmeal.

Table 6.8b. Volatile fatty acid production (moles/d) in the rumen for the diets in Table 6.8a. (Ortigues, 1987)

	B	BF	Bb	BbF
Acetate	8.31	8.20	11.12	9.35
Propionate	2.00	1.94	2.88	2.19
Butyrate	1.12	1.06	1.59	1.34
Pr:Ac	1:4.16	1:4.23	1:3.88	1:4.29

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6.3. ESTIMATION OF THE SUPPLY OF EXOGENOUS GLUCOSE PRECURSORS AND THE MAXIMUM POTENTIAL GLUCOSE PRODUCTION FROM THESE PRECURSORS FROM THE DIETS USED IN THE PRESENT EXPERIMENTS

In the following sections estimations are made of the supply of exogenous glucose precursors (propionate, amino acids and starch digested in the small intestine) and the maximum potential for glucose production from these sources for the diets used in each of the present experiments.

The main precursors of glucose have been discussed earlier. In summary, glucogenesis occurs mainly in the liver and kidneys from propionate. lactate, pyruvate, glycerol and amino acids. In fed animals, propionate and amino acids are the main precursors. 0.40 - 0.60 of glucose may be derived from propionate in fed animals and 0.30 to 0.50 of glucose could be synthesised from amino acids. It has been demonstrated that at least 0.12 of milk lactose is synthesised from glucose derived from amino acids. More recent work suggests that lower levels of glucose are derived from amino acids (<0.05). Lactate is not normaly detected in the rumen, and that which is present is usually converted to propionate by microrganisms. In working animals, pyruvate is reduced to lactate, which can be recycled to glucose. In starved animals glycerol can replace most of the propionate. Glycerol levels are normally low, but in periods of fat mobilisation glycerol released from adipose tissue enters the glycolytic pathway as dihydroxyacetone phosphate and is synthesised to glucose mainly in the liver. Up to 0.23 of glucose has been shown to be synthesisd from glycerol in starved sheep.

The glucose supply determined from the following calculations is compared with the calculated requirement for glucose. It is assumed that any deficit will be met from glycogen or glycerol from the breakdown of adipose tissue.

6.3.1. PROPIONATE SUPPLY AND POTENTIAL GLUCOGENESIS FROM PROPIONATE

For the estimation of propionate production, an average level of 2.5 moles/kgDDM is assumed from the range of levels of production (0.8 to 3.8 moles/kg DDM) summarised by Sutton (1985). However, Sutton suggests that maize diets would result in a 14% decrease in dry matter digested in the rumen, which would represent an overall decrease in VFA production and similarly states that propionate production on a 10:90 hay barley diet would be approximately twice that on a 40:60 hay concentrate (barley or maize) diet. Thus a differential propionate production is assumed for the diets in the present experiments, with production for diet HS1 being above average (3.0 moles/kgDDM) compared with average levels for diets AA6 and DF (2.5 moles/kgDDM) and below average levels for diets HS2 and HP (2.0 moles/kgDDM). Further it is assumed that a maximum of 60% of propionate is used for glucose production (Wiltrout and Satter, 1972) and that two moles of propionate are used to produce one mole of glucose.

Glucose requirements have been calculated using the equation: Glucose Flux (g/d) = 72 x Milk Yield (kg/d) + (370 x 1.44) (Konig, 1982).

The glucose requirement derived using this equation is shown in Table 6.9 and the estimated production of propionate for each diet during the non-walking period is shown in Table 6.10. Equivalent values for the walking period are shown in Appendix 8C.

Table 6.9. Estimated glucose requirements (g/d) for animals on each diet in the non-walking period prior to walking[1]

Experiment	I	II	II	III	III	III
Diet	AA6	AA6	HS1	HS2	DF	HP
Milk Yield (kg)	5.89	7.15	8.17	4.67	2.88	4.02
Glucose Requirement (g/d)[2]	956.9	1047.6	1121.0	869.0	740.2	822.2

1. For Experiment I the values are the mean values for both non-walking periods. For Experiments II and III the values are for the non-walking period prior to walking
2. Glucose Flux = 72 x Milk Yield + (370 x 1.44)

Table 6.10. Estimation of propionate supplied by each diet and potential glucogenesis from propionate

Experiment	I	II	II	III	III	III
Diet	AA6	AA6	HS1	HS2	DF	HP
Digestibility %	66	66	70	60	70	60
DMI (kg)	9.3	10.6	9.6	7.2	7.3	7.6
DDM (kg)	6.1	7.0	6.7	4.3	5.1	4.6
Propionate (moles/d)	15.3	17.5	20.1	8.6	12.8	9.2
Glucose Produced (moles/d)	4.6	5.3	6.0	2.6	3.8	2.8
Glucose (g/d)	828.0	954.0	1080.0	468.0	684.0	504.0

6.3.2. METABOLISABLE PROTEIN SUPPLY AND POTENTIAL GLUCOGENESIS FROM PROTEIN

Rumen degradable protein supply is estimated by two methods: a) by using the equation RDP = 8.4ME (ARC, 1980) and b) from values for crude protein and degradability for the protein supplied by each diet. Undegradable protein supply to the small intestine is calculated from the value for degradability for the particular diets. It is assumed that 0.2 of microbial protein is non-protein nitrogen, that 0.85 of microbial protein and undegradable protein digested in the small intestine is absorbed and 0.80 of protein absorbed is utilised by the tissues. Protein supply is shown below.

Table 6.11. Estimation of protein supplied by each diet in Experiments I, II and III

Experiment	I	II	II	III	III	III
Diet	AA6	AA6	HS1	HS2	DF	HP
ME Intake (MJ)	96.1	110.1	108.4	66.7	60.3	61.3
RDP (ME x 8.4) (g)	807.3	924.8	910.6	560.3	506.5	514.9
RDP (dg x CP) (g)	1012.9	1213.9	1099.4	606.7	607.1	618.9
TMP Supplied[1]	439.2	503.1	495.4	304.8	275.5	280.1
UDP Supplied	337.6	404.7	366.5	132.5	132.0	771.3
Metabolisable Protein from UDP	229.6	275.2	249.2	90.1	89.8	524.5
Total Metabolisable Protein Supply (g)	668.8	778.3	744.6	394.9	365.3	804.6

1. From TMP = RDP (ME x 8.4) x 0.85 x 0.80 x 0.80

The RDP supply calculated from the degradability and CP values were all greater than the amount of RDP required to balance ME supply and hence the lower value calculated from the equation RDP = ME x 8.4 was used in the final calculation.

Protein requirements are calculated according to values provided by ARC (1980) for maintenance (EUN = 2188mg/kg$^{0.75}$), hair (112mg/kg$^{0.75}$), milk (milk protein content x milk yield), growth (tissue protein requirement reduced by 56g for a weight loss of 0.5kg and increased by 75g for a weight gain of 0.5kg) and growth of concepta (50.0 g/d at day 179). The protein requirements are shown in Table 6.12. The potential glucose production from amino acids, if all amino acids were used for glucogenesis at a rate of 0.58kg glucose per 1.0kg protein (Girdler, Thomas and Chamberlain, 1986), is also calculated.

Estimates of glucose supply from amino acids have ranged from 0.05 to 0.50. An average value of 30% of glucose supply from amino acids is therefore assumed.

The glucose supply from propionate and amino acids and the requirement for glucose are summarised in Table 6.13.

The supply of glucose from propionate was not enough to meet requirements, but excess amino acids were available on some diets for glucogenesis. The potential glucose supply from these amino acids would be enough to meet the mean glucose requirements for animals on three diets, AA6 for Experiments I and II and the high starch diet (HS1) in Experiment II, but not for animals on diets HS2, DF and HP in Experiment III.

Table 6.12. Protein requirements (g/d) for animals on each diet in Experiments I, II and III

Experiment	I	II	II	III	III	III
Diet	AA6	AA6	HS1	HS2	DF	HP
Body Weight (kg)	444	523	517	493	495	512
$BWt^{0.75}$	96.7	109.4	108.4	104.6	104.9	107.6
Milk Yield (kg)	5.89	7.15	8.17	4.67	2.88	4.02
Milk Protein Content (g/kg)	29.1	36.8	38.8	30.4	35.0	41.5
Bodyweight Change (kg/d)	+0.76	+0.66	+0.60	+0.50	0.0	+1.1
EUN (g/d)	211.5	239.4	237.2	228.9	229.5	235.4
Hair (g/d)	23.7	27.2	27.1	25.8	25.5	26.9
Milk (g/d)	171.4	263.1	317.0	141.9	100.8	166.8
Growth (g/d)	+114.0	+99.0	+90.0	+75.0	0.0	+165.0
Growth Concepta (g/d)	50.0	50.0	50.0	50.0	50.0	50.0
Total Requirement	570.6	678.7	721.3	521.6	405.8	644.1
Protein Supply (from Table 6.11)	668.8	778.3	744.6	394.9	365.3	804.6
Excess (g/d) to requirement	98.2	99.6	23.0	0.0	0.0	160.5
Potential Glucose Supply (x 0.58)[1] (g/d)	57.0	57.8	13.3	0.0	0.0	93.1

1. Assuming that all amino acids are glucogenic and are used for glucogenesis.

Table 6.13. Summary of the potential glucose supply (g/d) from propionate and amino acids from each diet in Experiments I, II and III

Experiment	I	II	II	III	III	III
Diet	AA6	AA6	HS1	HS2	DF	HP
Glucose Requirement (g/d)	956.9	1047.6	1121.0	869.0	740.2	822.2
Maximum Glucose Supply from Propionate (g/d)	828.0	954.0	1080.0	468.0	684.0	504.0
Maximum Glucose Supply from Amino Acids (g/d)	57.0	57.8	13.3	0.0	0.0	93.1
Total Maximum Supply from these Sources	885.0	1011.8	1093.3	468.0	684.0	597.1
Balance (g/d)	-71.9	-35.8	-27.7	-401.0	-56.2	-225.1

The remaining glucose required could be supplied from starch digested in the small intestine. Diet HS2 in Experiment II was formulated to include a supply of starch to the duodenum from ground maize. It is also ,likely that some starch from the barley in diet HS1 would also pass unfermented to the duodenum to supply additional glucose.

6.3.3. POTENTIAL GLUCOSE SUPPLY FROM STARCH DIGESTED IN THE SMALL INTESTINE

The contribution of starch digestion in the small intestine to total glucose supply has been discussed in sections 3.3.2. and

6.2.3. In this section an estimation is made of the potential glucose absorption from the small intestine for each diet in the experiments. It is assumed that over 90% of starch is usually fermented in the rumen, but that on the diet containing maize approximately 25% of the starch escapes rumen fermentation (Lindsay, 1970; Oldham and Sutton, unpublished; quoted by Sutton, 1985). It is further assumed that more than 75% of post-ruminal digestion occurs before the caecum (Sutton, 1985).

The starch contents of each diet, the estimated amount of starch digested in the small intestine and the glucose production from this are shown in Table 6.14 for each diet.

Table 6.14. Starch supply to the small intestine and the potential glucose production from this for each diet

Experiment	I	II	II	III	III	III
Diet	AA6	AA6	HS1	HS2	DF	HP
Starch Content (g/kgDM)	202	202	300	525	224	130
Duodenal Starch (g/kgDM)	20.2	20.2	30.0	146.9	22.4	13.0
Total Duodenal Supply (g/d)	186.9	214.1	228.0	528.8	80.4	46.9
Pre-Caecal Digestion (g)	140.2	160.6	171.0	396.6	60.3	35.2
Balance from Pr + AAs	-71.9	-35.8	-27.7	-401.0	-56.2	-225.1
Final Balance (g/d)	+68.3	+124.8	+143.3	-4.4	+4.1	-189.9

All animals were gaining weight during the non-walking periods. When animals walked, weight losses were recorded for animals fed diets AA6 in Experiment II and diets HS2, DF and HP in Experiment III. The calculated glucose requirement does not take into account the extra demand for glucose for exercise. Cows fed diets AA6 and HS1 appear well prepared for exercise, but cows fed diets HS2, DF and HP appear to be less well prepared in terms of glucose supply.

The comparative glucose balances for animals during the walking period are shown in Appendix 9 and are summarised for animals fed each diet in Table 6.15 below.

Table 6.15. Glucose balances (g/d) for animals fed each diet in each experiment during the walking period

Experiment	I	II	II	III	III	III
Diet	AA6	AA6	HS1	HS2	DF	HP
Glucose Balance (g/d)	+153.4	+247.6	+225.9	+60.2	+56.3	-41.1

This balance indicates by comparison with the balance shown in Table 6.14 for non-walking animals, that glucose was made available when animals were walking from reduced milk synthesis, reduced body weight gain and body fat mobilisation. The amount of glucose required for exercise has not been quantified.

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GENERAL DISCUSSION

CHAPTER SEVEN

DISCUSSION

7.1. INTRODUCTION

The effects of exercise on physiological and metabolic functions are many, but less is known about the effects in cattle than in man and horses which have received more attention (Pearson and Archibald, 1989). The overall consequences of exercise include short-term stress, increased fitness, increased metabolic rate (short-term), increased energy requirement, changes in the ratio of blood metabolites and subsequent consequences for other productive functions.

When animals exercise they become fitter. This involves physiological changes such as increased cardiovascular rate, increased muscle tone, changes in lean to body fat ratio, effects on digestive function and reduced long-term metabolic rate. Exercise also has short-term effects on energy balances and blood metabolite levels characterised by a drain on blood glucose and acetate, the depletion of glycogen stores and the stimulation of free fatty acid mobilisation. The replacement of body stores after exercise is associated with short-term increases in metabolic rate. In untrained animals exercise may cause short-term physiological stress characterised by increased body temperature, increased respiration rate, fatigue and energy expenditure to maintain homeostasis.

The primary effects of exercise on the physiology and

metabolism of the ruminant animal underlie the responses in performance observed in the present experiments, and where relevant will be considered in the following discussion.

The results of the experimental work carried out will be discussed under the following general headings:

- the effect of exercise on milk yield
- the differential effect of exercise over time
- factors associated with the response to exercise
- the effect of exercise on blood metabolite concentrations
- the effect of exercise on milk constituent concentrations and yields
- the effect of diet on the response to exercise
- the effect of exercise on body weight changes
- the effect of exercise on food intake
- the partition of energy for exercise and lactation.

The implications of the present work for other cattle breeds, cattle in different environments, different feeding regimes, increased work loads, cows working at different stages of lactation and for the management of draught cows also will be considered.

7.2. THE EFFECT OF EXERCISE ON MILK YIELD

In Experiment I milk yield was reduced by 10.7 percent as a result of exercise. This result was confirmed in Experiments II and III and a significant difference was demonstrated between milk yields of the walking and non-walking groups of cows in all experiments. Milk yield was depresssed by exercise by between 7 percent and 14 percent in these three experiments. These results

were for the whole data and included milk yield values for non-walking days. If the values for non-walking days were removed, the mean depression due to exercise was slightly greater.

The results agree with those of Rizwan-ul-Muqtadir *et al* (1975) who found that working caused a 14 percent drop in milk yield in working female buffaloes. These animals ploughed with a single neck harness and a traditional short beam plough for three hours per day at speeds of between 2.1 and 2.9 kilometres per hour. Other authors (Kibria, 1982; Goe, 1983; Jabbar, 1980) have reported that exercise affects milk yield in working cows, but levels of reduction were not specified by these authors.

The levels of response demonstrated in the present experiments were lower than those of Barton (1987b) who found that over a five week working period, cows in Bangladesh in the second month of their first lactation lost between 23 and 40 percent of their milk yield. These animals were yoked in pairs and pulled traditional country ploughs for two to three hours a day (maximum of 19 hours per week or 95 hours over five weeks) at average speeds of 2.2 kilometres per hour. Although the animals in the present three experiments did not pull ploughs, other aspects of their work regime were similar. They walked for three hours a day (maximum 15 to 17 hours per week or 45 to 51 hours over three weeks) and walked at average speeds of 2.9 kilometres per hour. Similarly, Tornede (1939) reported that in cows ploughing in pairs for up to eight hours per day in Germany heavy work can cause up to an 80 percent fall in milk yield.

Rizwan-ul-Muqtadir *et al* (1975) fed their animals a balanced

ration containing 13 percent DCP given according to requirement, whereas Barton fed *ad libitum* alkali treated or untreated rice straw with 1kg fresh grass and 300g concentrate. The level of nutrition may affect the response to exercise and this will be discussed in section 7.7.

7.3. THE DIFFERENTIAL EFFECT OF EXERCISE ON MILK YIELD OVER TIME

As well as the absolute effects of exercise on milk yield as described above, it is also possible to distinguish differences in the response to exercise over time. The exercise regime was largely the same in all the present experiments in terms of the total exercise carried out over the three week period. In Experiment III the animals walked slightly less during the first week, but this was compensated for during the following two weeks. As a result, the energy expenditures over the full walking periods in each experiment were similar.

The variations in milk yield response over the full walking periods fell into patterns which occurred in each experiment. The declines were greatest on the first walking days in each walking week. Over the three week walking period with two resting days between each five day walking period, an adjustment in the milk yield response to exercise was observed in which animals lost less milk in successive walking weeks. The pattern of response however, was not consistent between experiments. In Experiments I and III the overall effect of exercise on milk yield increased in successive weeks, but in Experiment II the effect decreased. This difference can best be explained by the moderating effect of the

high starch (barley) diet (HS1) on the response of milk yield to exrecise in Experiment II.

The cows had been housed all winter, and the reduced milk yield recorded during the first few days of walking could be accounted for by a combination of unfitness, general stress (as a result of exercise), energy deficit or nutrient imbalance. The milk yields of animals throughout the walking periods declined steadily relative to the milk yields in control periods. For high roughage diets (barley straw) and high starch diets (barley and maize), the weekly declines were relatively constant, or decreased to less than 20 percent per week. For the high protein and digestible fibre diets the decline increased from approximately 20 percent per week in week one to 25 to 29 percent in week three. It can be assumed that the sustained milk yield reductions which were observed, were therefore the result of more than initial shock and unfitness.

It was intended to extend the length of the exercise period in Experiment III, but as the experiment progressed, the milk yields of a number of cows began to decline rapidly and it became apparant that they would dry-off before the planned end of the experiment. To avoid this, the exercise period was terminated after three weeks in Experiment III as in previous experiments.

When animals were not walked at weekends, the yield recovered on each day of the weekend and then declined again when walking re-commenced, even though animals were becoming fitter and were less likely to suffer adverse effects of stress from the exercise regime. The recovery of milk yield on resting days was very quick and after two days yields had often returned to the same level as

at the beginning of the previous five day walking period. Milk yield responded very quickly to exercise or to periods of rest.

The effect of exercise on milk yield over periods longer than three weeks was not investigated. Barton (1987b) worked animals continuously for five weeks and found a greater milk yield decline than demonstrated in the present experiments. The daily work carried out by animals in the present experiments was similar, if not greater than that carried out by Barton's animals (3 hours per day at 2.1 kilometers per hour compared with three hours at 2.9 kilometers per hour). Barton's animals also pulled a plough and so even though the speed was less, the energy expenditure may have been greater. The greater decline observed by Barton could be explained by the longer overall working period, the absence of resting days or by the diet, which may have been poorer than in the present experiments. Rizwan-ul-Muqtadir *et al* (1975) worked their animals continuously for 21 days and found a similar decline as in the present experiments.

7.4. FACTORS ASSOCIATED WITH THE RESPONSE TO EXERCISE

Under different circumstances, the response of milk yield to exercise might be different than was observed in the present experiments. Low levels of exercise may have a beneficial effect, greater levels of exercise may have a disproportionately greater effects and animals at different physiological stages (ie. early lactation) may respond differently from the present cows.

7.4.1. THE STIMULATORY EFFECT OF EXERCISE ON MILK YIELD

A converse effect of exercise has been suggested by Anderson *et al* (1977) who considered that moderate exercise in high yielding dairy cows has a beneficial effect on yields by stimulating feed intake, particularly after parturition. Tornede (1939) also reported that light work can stimulate milk production. In the present experiments there was no proper opportunity to test this. The present cows were in late lactation and not immediately post parturiant. Further, in Experiments I and II there was no possibility for cows to increase food intake as they were rationed individually in relation to their initial milk yield and body weight. In Experiment III, straw was offered *ad libitum*, but exercise did not increase voluntary consumption of this forage, even though the cows received supplements which may have favoured this possibility. Although it remains a possibility that light work may have a beneficial effect by stimulating feed intake, this has not been demonstrated in the present experiments.

7.4.2. TOTAL DAILY ENERGY EXPENDITURE

The response to exercise depends partly on the daily energy expenditure resulting from exercise. In the present experiments, the ME equivalent of exercise was approximately 12 MJ/d. For a 450kg cow this amounts to 25 percent of maintenance energy requirements (MAFF, 1975) over a 24 hour period. This is a low level of energy expenditure compared with levels of 50 percent of maintenance recorded by Barton (1987b), 75 percent of maintenance

quoted by Starkey (1981) and upto 150 percent of maintenance quoted by Lawrence and Mathers (unpublished). These energy expenditure levels were reported for oxen carrying out farm work such as ploughing and pulling carts for periods of a few hours each day. The main energy matabolites required to supply the needs of working muscles for such work would be acetate, free fatty acids and glucose. These requirements would not compete with other productive functions in such working oxen. In female lactating and/or pregnant animals however, high levels of work would increase the competition for metabolites, and it might be expected would have more serious consequences for lactational performance, as indicated by the greater milk yield declines demonstrated by Barton (1987b). The levels of response (up to 14 percent) demonstrated in the present experiments are probably low compared to the levels of response that might be expected in tropical draught cows.

7.4.3. DIURNAL VARIATION IN RATE OF MILK SECRETION

Although it was not measured in the present experiments, the rate of milk synthesis may be lower when animals are working and in the period after work, as a result of lowered blood glucose levels and competition for other metabolites. The lowest synthesis rate may occur during the work period when competition for metabolites is greatest and when blood concentrations of metabolites are low. Competition for metabolites at other parts of the diurnal cycle resulting from exercise may also exist, since body stores utilised for work must be replaced later. Lawrence, Buck and Campbell (1989) have demonstrated that in animals fed at 0.7 maintenance, the

metabolic rate 17 hours after exercise was on average 8.2 percent higher than for the two day period prior to exercise. They explained the higher metabolic rate as a consequence of continued resynthesis of body reserves after work. Under such circumstances, nutrient competition may be spread over a longer period through the day.

7.4.4. PERIOD OF LACTATION

The cows in the present experiments were in late lactation (eight months plus) and milk yields were declining. All cows were approximately five months pregnant at the beginning of the experiments and the physiological state of the cows did not favour sustained milk production. Even so, milk yields showed resiliance and an ability to return to near previous levels on non-working days and after the working period had finished. Some carry-over effect was seen in the first experiment.

It is likely that the effects on milk yield demonstrated in these experiments would be exaggerated in cows worked earlier in lactation when nutrient supply would be more critical than in later lactation. In early lactation there would be a higher demand for glucose compared with a higher demand in later lactation (as pregnancy progresses) for amino acids. Barton's cows (Barton, 1987b) were in the second month of lactation and suffered a 23 - 40 percent decline in milk yield.

7.4.5. REPRODUCTION AND FERTILITY

The effects of exercise on fertility, parturition and birth

weight of calves have not been discussed, but their importance in draught cow management should not be overlooked.

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7.5. THE EFFECT OF EXERCISE ON BLOOD METABOLITE CONCENTRATIONS

The measurement of changes in blood metabolite levels during and after exercise can help to indicate changing energy demands during exercise and work and the physiological responses to such demands. The responses measured in the present experiments will be discussed in relation to the expected patterns of nutrient supply of skeletal muscle during sustained work as discussed by Bird *et al* (1981), Pethick (1984) and Leng (1985). The muscle's glucose requirement is obligatory and increases by approximately 50 percent over two hours of exercise in sheep. The contribution of muscle triglyceride and glycogen stores decreases over time, whereas the contribution of acetate is relatively constant and the contribution of energy from ketones and free fatty acids increases.

In the present experiments, the onset of walking had quite dramatic effects on the biochemistry of the animals. β-OH butyrate and free fatty acid levels increased on all diets when the animals walked and blood glucose levels fell. Urea levels increased on some diets and albumin showed a decrease whereas globulin showed no change. Magnesium and phosphorus also decreased in the walking period. The energy status of animals on the less energy dense diets such as diet AA6 in Experiment II were less favourable than for animals which received more energy dense diets.

The results of the present experiments are similar to the changes in blood metabolite balance found during exercise in cattle and buffaloes by Singh, Soni and Bhattacharyya (1968), Georgie, Sastry and Razdan (1970), Hays, Bianca and Naf (1978), Nangia, Rana, Singh and Ahmad (1978), Upadhyay and Madan (1985) and Pearson and Archibald (1989). Resting levels were within normal ranges shown in Appendix 4A and reported by Baird (1977), Collins and Kelley (1977) and Swaid, Sing, Sastry and Georgie (1986).

One hour of exercise in oxen has been shown to affect levels of glucose, free fatty acids, β-OH butyrate and inorganic phosphorus, though the changes were short-lived and values had usually returned to resting levels by 75 minutes after exercise stopped (Pearson and Archibald, 1989). No effect was found by these authors on levels of albumin, urea or magnesium.

7.5.1. β-OH BUTYRATE

β-OH butyrate levels are on average 0.42mmol/l in fed lactating cows , but are quantitatively more important in starved lactating cows (2.86mmol/l) when the contribution of free fatty acid to ketone production increases (Baird, 1977). Increased β-OH butyrate levels can be taken as an index of body lipid mobilisation. Under extreme conditions this causes the condition commonly known as ketosis (or acetonaemia). Ketosis is normally associated with animals fed inadequately or given insufficient energy supply in early lactation when the demand for glucose is high, but cannot be met from dietary sources.

In the present experiments blood concentrations on high starch

diets increased when animals walked, but levels increased more in animals on the high roughage diets. The high starch diets in both experiments had the lowest β-OH butyrate levels in the walking periods. Levels increased from approximately 0.5 to 1.6mmol/l when animals walked.

β-OH butyrate utilisation by skeletal muscle has been shown to increase when animals exercise (Pethick, 1984), though the total contribution to muscle energy demands is relatively small compared to other energy substrates. Since the lowest β-OH butyrate concentrations resulted from high starch diets, this might indicate that these diets resulted in a lower glucose stress than on high roughage or high protein diets.

7.5.2. FREE FATTY ACIDS

Blood concentrations of free fatty acids increased during the walking period in both experiments. Free fatty acid levels in animals on high roughage diets in Experiment II were higher than for animals on high starch diets, but in Experiment III levels in animals on high starch diets were higher than in animals on other diets (significantly for the high protein diet). The increases when animals exercised suggest that lipid mobilisation occurred to meet increased energy demands for skeletal muscle activity.

Davis and Collier (1985) have noted that free fatty acid concentrations in bovine plasma vary inversely with feed intake and are elevated by mild excitement. Part of the increase observed in the present experiments could be due to 'excitement' caused by the daily exercise routine. Pearson and Archibald (1989) also found

that free fatty acid and β-OH butyrate levels increased during exercise, and that concentrations returned to resting levels 45 minutes after work had finished. In the present experiments blood samples were taken between 15 and 45 minutes after walking had ceased (ie blood was taken from the first cow 15 minutes after walking had ceased and from the last cow 45 minutes after walking had ceased). The level of exercise in the present experiments was triple the duration compared to that of Pearson and Archibald (1989) and β-OH butyrate levels were still considerably higher after work in the present experiments than those recorded by these authors, despite the time lag of taking samples

In fed ruminants acetate rather than free fatty acids is the more important energy source for resting skeletal muscle (Bickerstaffe *et al*, 1974; Bird *et al*, 1981). The responses seen in the present experiments appear to conform to the expected change in nutrient supply to working skeletal muscle as described by Jarret *et al* (1976) who emphasised the increased importance of free fatty acids for working skeletal muscle.

7.5.3. UREA

Blood urea concentrations increased during the walking period in Experiment II, and in the later part of the walking period in Experiment III.

Increased blood urea levels when the animals walked might be explained by the catabolism of protein for glucogenesis, or high levels may be caused by increased rumen ammonia production on diets with high levels of fish meal (Tamminga *et al*, 1979). This would

explain the increased blood urea levels on diet HP (high fishmeal) throughout the first control period in Experiment III. In animals fed this diet, the urea concentrations appeared to continue to increase throughout the experiment, with some reduction by the end. This may indicate a slow adaptation of the animals to this diet throughout the experimental period, with proper adjustment only occuring towards the end of the experiment. These animals also gained weight faster and ate more straw than animals fed other diets. The protein demand for pregnancy also increases blood urea.

7.5.4. GLUCOSE

Blood glucose concentrations fell in the present experiments when animals walked, but the effect of exercise appeared to diminish with time. These results agree with those of Pearson and Archibald (1989) who found that over a one hour walking period blood glucose levels dropped during the first ten minutes and then began to rise throughout the rest of the walking period, but had not reached resting levels 75 minutes after the end of exercise. The effect of moderate exercise (one hour) in pregnant ewes has been shown to increase blood glucose concentrations (Chandler and Bell, 1981). These authors explained this as the result of increased hepatic glycogenolysis due partly to increased pancreatic glucogon secretion.

In the present experiments the greatest decrease in blood concentration was a 21.9 percent decrease during the first week of walking in Experiment II and a 16.0 percent decrease in the second week of walking in Experiment III. In the final week of the

exercise period the concentration was 2.5 percent higher than the mean control value in Experiment II and only 9.0 percent lower than the mean control value in Experiment III. Since no estimations of changes in blood volume were made, changes in metabolite concentrations cannot be related to possible blood volume changes that may have occurred.

The decrease in blood glucose concentrations when animals walk could be explained as the result of an absolute glucose deficiency arising from the animal's inability to supply glucose from exogenous and endogenous sources to meet the increased demands of exercise. The blood samples in the present experiments were taken up to 3½ hours after the commencement of exercise when the animals had returned to their stalls and were resting. The animals were fed at the morning milking between 2½ and 3½ hours before the commencement of the exercise period and in Experiment III the animals also had *ad libitum* access to straw. At the beginning of the exercise period it is likely that the animals were absorbing metabolites (acetate and propionate, β-OH butyrate, lipids, amino acids and possibly glucose) from the rumen and small intestine. If the supply of metabolites from the digestive tract diminished throughout the exercise period this would put a greater demand on endogenous sources of glucose (stored glycogen and glucose formed in the liver, kidneys and other tissues). If this were the case, it must be concluded that the supply of glucose for sustained exercise in these experiments could not keep pace with demand and that blood glucose concentrations decreased as a result. This is supported by the finding of Pethick *et al* (1987) that the contribution of

endogenous fuels (glycogen) to muscle energy supply was calculated from empirical evidence to decline to zero after two hours of exercise.

The observation that the response to exercise was greatest in the first or second week of exercise, but that the response decreased over time, may be explained in a number of ways. One explanation might be that the greater reductions in blood glucose concentration in the first week of exercise were due to greater energy expenditure as a result of increased pulmonary and vascular activity due to unfitness. This explanation is supported by the work of Hays, Bianca and Naf (1978) who found that in oxen there was a training effect which resulted in a subsequent reduction in exercising heart rate, respiratory rate and rectal temperature.

Alternatively, animals might use less energy to achieve the same work output as they become more used to the work or the exercise routine, as a result of better coordination and less wasted effort due to stumbling and uncertainty of gait.

Energy saving with increased fitness however, may be offset by increases in energy expenditure associated with fitness and exercise. As animals become fitter their overall resting metabolic rate decreases, but Lawrence, Buck and Campbell (1989) have reported that metabolic rates can remain high after exercise on account of extra energy expenditure needed to resynthesise body reserves. This theory is consistent with the findings of Goldberg *et al*, (1988) whose human subjects fed at maintenance showed an increase in resting metabolic rate after work which depended on the amount of work done during the day.

Alternatively the observations may indicate a physiological adjustment to exercise which results in 'glucose sparing'. This would be in agreement with observations of human subjects in which a consequence of exercise has been shown to be a shift of metabolism toward a greater use of fat resulting in glycogen sparing (Gollnick, 1985).

A shift from a dependence on acetate by resting skeletal muscle to free fatty acids in working muscle has been described by numerous authors (Jarret *et al*, 1976; Bird *et al*, 1981; Pethick *et al*, 1987). Exercise has been shown to increase the activity of lipoprotein lipases which breakdown triglycerides into free fatty acids and glycerol (Borensztajn and Robinson, 1970). The reduced decrease of blood glucose concentration over time could be a further adjustment in 'fitter' animals to a greater utilisation of fatty acids.

In horses fed fat, blood glucose concentrations after work are higher than in animals not fed fat and a 'glucose sparing' mechanism appears to operate as a result of diet (Duren, Jackson, Baker and Aaron (1987). A possible explanation for the increased utilisation of fat may be increased oxidative metabolism in muscle indicated in man by increased mitochondrial protein and increased activitiy of the enzymes associated with citric acid cycle and oxidative phosphorylation (Ingjer, 1979). Therefore the body may adapt by modifying enzyme systems to utilise different ratios of energy substrates (Duren *et al*, 1987). Mechanisms such as these may have been operating in the cattle used in the present experiments, but the situation is by no means clear.

Pethick *et al*, (1987) considered the implications of the shift from acetate to fatty acid utilisation in working muscle for glucose utilisation and considered that the control of glucose utilisation warrants further investigation. They noted the observations made by Newsholme (1976) that fatty acids may actually inhibit glucose utilisation by skeletal muscle.

7.5.5. BLOOD ALBUMIN AND GLOBULIN

Neither diet nor work had statistically significant effects on blood globulin concentrations in either of the present experiments, though decreases were observed in the first walking week of both Experiments II and III. High globulin concentrations were observed in some cows in some weeks and these would suggest non-specific infections such as mastitis. Albumin:globulin ratios of 6.0 or below would indicate the presence of chronic inflamatory disease.

Blood albumin levels in the present experiments were affected by exercise. In Experiment II, concentrations increased slightly when animals walked, but levels decreased when animals walked in Experiment III. The differences between the experiments may have been due to diet, particularly prior to the experiment. In Experiment II, low albumin concentrations in the first three weeks may have been due to low dietary protein status prior to the experiments and higher levels later in the experiment the result of adjustment to the better diet. The results of Experiment III show a consistent decline as animals walked, and are probably a more reliable reflection of the effect of sustained exercise. Shorter durations of work however, carried out by Pearson and Archibald

(1989), had no effect on serum protein and albumin concentrations, which was interpreted as indicating that fluid shifts from the blood are unlikely to occur with short duration work.

7.5.6. INORGANIC PHOSPHORUS AND MAGNESIUM

Decreases in phosphorus and magnesium were observed in the present experiments as a result of exercise. Decreases in magnesium (and phosphorus in some animals) in working buffaloes were also reported by Agarwal, Singh, Agarwal and Dwaraknath (1982). These reductions may be related to the increased use of both minerals in the processes associated with increased energy metabolism during exerecise.

Phosphorus plays a vital role in energy metabolism in the formation of adenosine di- and tri-phosphates (ADP and ATP) from adenine and the sugar D-ribose. Phosphorylation of the hydroxyl group of the C5 atom of the sugar produces adenosine mono-phosphate and successive additions of phosphate residues produces ADP and ATP. Decreased blood phosphorus concentrations in exercising ruminants may be an attempt to re-establish intracellular phosphate reserves or may result from increased carbohydrate metabolism in response to exercise (Codazza, Maffeo and Redaelli (1974).

Magnesium is the commonest enzyme motivator in animal tissues. It is particularly important in activating phosphate transferases, decarboxylases and acyltransferases. The magnesium levels in the present animals were constantly monitored and a daily supplement given with the feed. There was no reason to believe that the animals were deficient and no signs of hypomagnesaemia were seen.

In future research using cows for draught, close attention to the effect on micronutrient balance would be appropriate, particularly at high levels of work.

7.5.7. DURATION OF BLOOD METABOLITE CONCENTRATION CHANGES

The duration of the changes was not investigated in detail in the present experiments. Blood samples were taken after 3 hours of exercise on the third day of five consecutive days of walking. The changes observed represent the immediate response to the exercise on the day of sampling. Changes in the first walking week were usually more pronounced than in subsequent weeks. The time at which samples are taken relative to finishing work can have a marked effect on the levels of some parameters, as many of the changes are of relatively short duration.

In order to determine whether blood metabolite levels remained the same when the animals did not walk on Saturdays and Sundays in the middle of the walking period, blood samples were taken for three additional days in Experiment III only at the end of week two of the walking period on a Friday, Saturday and Sunday at the same time of day as the other blood sampling. The results indicated that levels had begun to return to control levels on the day following five consecutive days of walking and that the effects were therefore of relatively short duration in these animals. This is in agreement with the results from Brahman x Friesian cattle which worked on a treadmill for one hour, in which blood metabolites returned to resting levels withing 75 minutes after work finished (Pearson and Archibald, 1989).

The animals in the present experiments did not appear to suffer any adverse effects of heat stress, and only on the first few days of exercise did the animals show any signs of panting or drooling. Such effects if observed would be expected to have some effect on blood metabolite levels (ie. free fatty acids and glucose) and may be important in tropical working animals where heat stress might be a bigger problem.

The effect of exercise on blood glucose concentrations over time can be correlated with the effects seen on milk yield over time, where the effect was lower in the later weeks of exercise.

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7.6. THE EFFECT OF EXERCISE ON MILK COMPOSITION

7.6.1. INTRODUCTION

In the present experiments it was found that when animals walked, lactose and milk protein yields declined in proportion the decline in milk yield, but milk fat yields remained relatively constant in walking and non-walking periods. These results differ from those reported by Rizwan-ul-Muqtadir *et al* (1975) who reported no effect on milk composition when animals carried out three hours of work per day over a twenty one day period, even though a decline in milk yield was recorded. Similarly, Barton (1987b) recorded no effect of work on solid not fats yield, but found an increase in milk fat content as milk yield declined due to work. The detailed effects of exercise on milk constituent yields and contents are discussed in the following sections.

7.6.2. MILK FAT

The analysis of total yields of milk constituents indicates that although there may have been an overall energy shortage or less than optimum metabolite balance for milk production, there was no shortage of energy or metabolites for milk fat production, which stayed relatively constant.

Milk fat content changed in inverse proportion to milk yield, so that as milk yield went down, milk fat content increased. Milk fat yield therefore was not greatly affected by exercise and animals on all diets were apparently able to maintain milk fat output, perhaps by mobilising adequate lipid resources to maintain

resting levels of milk fat synthesis. Milk fat yield (g/d) declined only relatively slowly or did not decline at all compared with the decline in milk yield. This was illustrated in Experiment II, in which diet AA6 produced the lowest milk yield, but the milk of cows receiving diet AA6 had persistently higher milk fat yields than cows receiving the high starch diet (HS1).

The high roughage diet AA6, which would be expected to produce higher rumen acetate levels (Oldham, Buttery, Swan and Lewis, 1977), produced higher fat contents and higher fat yields than diet HS1 in Experiment II. A similar relationship between the milk fat content of the milk of cows fed high starch diets compared with high fibre diets was also demonstrated by Annison, Bickerstaffe and Linzell (1974).

High fat contents and yields were also observed on other high roughage diets, particularly the high protein diet (HP) in Experiment III. A considerable proportion (0.30) of the ME content of the HP diet supplement was in the form of fishmeal and possibly half of this would not have entered the rumen fermentation process. It is likely that rumen energy production would not have been as high on the high protein diet as on the digestible fibre and high starch diets. The relatively lower level of rumen fermentation would promote higher acetate and hence higher milk fat levels than other diets. The relationship between high milk fat and high fishmeal diets has also been demonstrated by Robinson *et al* (1979) and Penning *et al* (1988).

High milk fat levels also may be related to body lipid mobilisation in response to the energy deficit when animals walked.

If body reserves are mobilised in circumstances of energy deficit, this may have a positive effect on milk fat synthesis, even though other milk constituents might be reduced as a result of inadequate precursor supply and reduced milk yield. If the blood triglyceride pool increases beyond the need of energy for exercise, the surplus triglycerides may be diverted into milk fat synthesis rather than to tissue lipid deposition.

Such an outcome of excess lipid mobilisation would be encouraged by the positive relationship which exists between yield of milk fat and free fatty acid content of the mammary venous supply (Davis and Collier, 1985). Increased blood free fatty acid concentration resulting from body lipid mobilisation might contribute to increased milk fat yield. A knowledge of the milk long chain fatty acid profile would help to determine the contribution of body fat to milk fat.

No attempt was made to measure the change in body composition of the animals in the present experiments, other than by assessment of body condition score. The condition scores were within the range of 1.75 - 2.50 and hence while not being excessively fat, the animals had body reserves available which could be used as a source of free fatty acids. The animals either maintained or lost condition in the experiments. Animals with low body fat reserves, such as cattle in the tropics, might not be able to maintain milk fat yields in the way the present animals did.

7.6.3. MILK PROTEIN

In contrast to milk fat yields, milk protein yields were

reduced significantly by exercise. The protein content of the milk remained relatively stable and as milk yield dropped, the yield of milk protein dropped accordingly. As a result the response of milk protein to exercise was similar to that of milk yield. In fact, the proportion of protein in the milk increased slightly over the experimental periods and protein yields decreased proportionately less than milk yields when the animals walked (9, 8 and 8 percent compared with 11, 9 and 10 percent for milk yields in each experiment).

The loss of milk protein yield could be explained in one of four ways: a) animals did not have adequate supplies of exogenous amino acids to supply lactational requirements, b) they could not mobilise amino acids quickly enough to supply requirements c) milk protein content does not vary or d) some other factor controls the secretion of milk protein.

Since the amino acid requirements for exercise are negligible (Lawrence, 1985a; Pearson, 1986), it is difficult to ascribe the decline of milk protein directly to an amino acid deficit arising from exercise.

Dietary amino acid supply has been shown to affect milk synthesis. Higher milk yields have been achieved on diets with a higher proportion of undegradable dietary protein (Oldham, Fulford and Napper, 1981; Gonzalez, Robinson, McHattie and Fraser, 1982; Penning, Orr and Treacher, 1988). These authors did not discuss the pathways through which amino acids influenced milk yield. In the work of Oldham *et al* (1981) milk yields were lower on non-protein nitrogen diets than on undegradable protein diets. Penning, Orr and

Treacher (1988) found that feeding rations containing high levels of undegradable protein not only increased the nitrogen content of milk, but also the fat and lactose concentrations in the milk. Amino acids from undegradable protein sources also may be used for glucogenesis.

Since the amino acid requirement for exercise is small and the diets in the present experiments were designed to meet normal requirements, the drop in milk protein can best be explained by the assumption that there was no amino acid deficit and that some other factor than dietary supply of amino acids was controlling milk protein synthesis. It may be that milk protein content is relatively constant and therefore milk protein yield will depend on milk yield. It is possible that milk protein secretion occurs in proportion to other milk constituent secretion, in particular lactose. Lactose yields fell by more than protein yields in all experiments and it is suggested that the depression of milk protein may have occurred as a consequence of the depression of milk yield resulting from a depression of lactose secretion.

Amino acids are glucogenic and amino acid supply may have been depleted by the use of amino acids for glucogenesis. If lactose secretion is the most important determinant of milk yield, as suggested by Rook, Storry and Wheelock (1965), then even if amino acids supply was not depleted by glucogenesis, amino acid supply would still play a secondary role to lactose secretion in controlling milk yield.

The depressing effect of exercise on protein yield, was partly alleviated by diet in Experiments II and III. The lowest decrease

in milk protein yield was seen on the high protein diet (HP) in Experiment III. This dietary compensation for milk protein however did not result in this diet having the highest milk yield. Hence, while protein supply might have had an independent influence on milk protein concentrations, this influence was not necessarily translated into an enhanced milk yield.

The energy/nitrogen balance also plays a role in determining the limiting metabolites for lactation as demonstrated by Robinson *et al* (1979). If energy is not limiting, increases in protein supply result in increased milk yield to the animal's genetic potential (Oldham and Smith, 1982).

7.6.4. LACTOSE

In the present experiments, when animals walked, lactose yields decreased by 11, 9 and 14 percent in each experiment respectively.

The decline of lactose can be explained most easily by a deficit of glucose and glucose precursors as a result of the greater demand for these during exercise. The contribution of glucose to oxidation in skeletal muscle during sustained exercise increases by up to 38 percent (Pethick, 1984). Bird, Chandler and Bell (1981) showed that glucose uptake by the exercising hind limb of the sheep more than tripled in maintenance fed sheep and more than doubled in sheep fed at 1.5 maintenance relative to the resting hind limb. Working animals, animals on restricted diets or animals eating high roughage diets with low CP contents are likely to be particularly prone to glucose deficiency.

It is likely that a closer relationship exists between the supply of glucose precursors and milk lactose synthesis than exists between amino acid supply and milk protein synthesis. The normal precursers for glucose in ruminants are propionate and amino acids. In fed lactating and non-lactating cows 45 - 65 percent of glucose originates from propionate (Wiltrout and Satter, 1972) and in fed sheep 27 - 54 percent of glucose synthesised originated from propionate (Bergman, Roe and Kon, 1966; Leng, Steel and Luick, 1967 and Lindsay, 1978). Amino acids may contribute 30 - 50 percent of glucose synthesis (Black, Egan, Anand and Chapman, 1968), but lower levels have been suggested by Oldham (1978). Further, as mentioned earlier, there is a more substantial demand for glucose for exercising muscle compared with the small demand for amino acids for exercise. As a result, lactose synthesis is likely to be affected more by nutrient supply than is milk protein synthesis.

The most important limiting factor to milk yield in the present experiments appeared to be the availability of lactose precursors, which conforms with the hypothesis that glucose supply is a major limiting factor to lactation in working ruminants (Leng, 1985). The diets which provided high levels of glucose precursors via propionate or starch had the highest milk yields in these experiments and resulted in the least depressing effect of exercise.

The high starch diets, which were designed to provide larger amounts of glucose precursors, resulted in relatively smaller declines within experiments in milk yield as a result of exercise than did other diets (Tables 5.5 and 5.10). The high starch diet

based on barley (HS1) in Experiment I produced a lower decline than the high starch diet based on maize (HS2), but these diets were fed in different experiments. Propionate production levels would be expected to be higher in animals fed the high starch (barley) diets, which would promote higher levels of glucose production as previously demonstrated by Annison, Bickerstaffe and Linzell (1974).

The barley high starch diet and the high protein diet also recovered better than other diets on resting days (Table 5.6) and were able to maintain milk yield better.

The effect of exercise on lactose yield was partly alleviated by the high starch diets and the lowest decrease in lactose in Experiments II and III was seen on the high starch diets (HS1 and HS2). These diets sustained higher milk yields overall (Table 5.3) as well as enabling the cows to support relatively high rates of milk secretion during exercise (Table 5.4).

It is not clear from the present experiments whether the deficiency in substrates (apparantly mainly glucose) for milk synthesis when animals were exercising was absolute or whether substrates could not be mobilised fast enough when animals were walking. There is the possibility that the animals were in glucose deficit during walking and that milk synthesis stopped during the walking period.

The changes in lactational performance which have been observed in the present experiments occurred in animals which were on average in the seventh month of pregnancy during the walking period of each experiment. Different responses might be expected in cows

at earlier stages of pregnancy or non-pregnant lactating cows. The demands which the concepta puts on maternal nutrient supply are considerable and are most severe in the last trimester when the mother's physiological state is largely catabolic (Oldham, 1985). Body reserves which have been built up during the anabolic phase of early pregnancy are broken down to meet the increasing foetal demands. Growth of concepta is a further drain on nutrients for which working muscle is a direct competitor. The conclusion drawn by Oldham (1985) was that an adjustment in nutrient use occurs in the third trimester to allow 'normal' development of the concepta by allowing increased use of maternal fat as a metabolic fuel with the possibility of net protein mobilisation from non-mammary maternal tissues. This is another example of glucose 'sparing' in order to ensure that the relatively limited supply of glucose can meet the animal's requirement, in this case for use by the foetus.

The present pregnant, lactating animals in all experiments appeared to cope well with the demands made upon their nutrient supply for maintenance, growth of concepta, lactation and muscle metabolism during exercise.

7.7. THE EFFECT OF DIET ON THE RESPONSE TO EXERCISE

A differential effect of exercise depending on the level of feeding has been suggested by some authors. Barton (1987) for example, found that draught cows fed alkali treated rice straw had a lower milk yield reduction than draught cows fed untreated rice straw. Even so, the milk yield reduction was still greater for these cows than in the present experiments. It is possible that

Barton's animals received diets which still produced a poorer supply or balance of nutrients than the diets in the present experiments. Alternatively the overall level of energy deficit may have been greater in these previous experiments.

Diet could influence the lactational response to exercise in a number of ways: by its influence on energy supply *per se*, by influencing the overall balance of energy yielding nutrients, or by influencing the supply of amino acids, minerals, vitamins or water. Of these, the dietary influence on total energy intake and balance of energy metabolites is likely to be of greatest importance. Water was constantly available and it is unlikely that the animals were dehydrated at any time in the present experiments. Similarly it is unlikely that vitamin deficiencies occurred on any of the experimental diets. Magnesium and phosphorus were measured in the experiments as discussed earlier. Magnesium levels were normal, but phosphorus levels decreased when the animals walked. Although there may be an increase in muscle volume, there is no convincing evidence that exercise or work significantly increase long-term protein needs (Lawrence, 1985b; Pearson, 1986) and exercise is assumed to have had little effect on amino acid supply in the present experiments. As previously mentioned, it would appear likely that the effect of exercise on milk yield is related mainly to an overall energy deficit or to an imbalance in energy substrates resulting from the exercise carried out. In the present experiments (I and II) the allowances offered to animals depended on their requirement for ME.

The main precursors of milk are glucose, amino acids, acetate,

β-OH butyrate, triglycerides and free fatty acids. Glucose is the major determinant of milk yield with amino acids having some influence on milk yield. At given levels of dietary energy input, amino acid supply and source of dietary nitrogen can also influence milk yield. The main energy metabolites for resting and working muscle are acetate, β-OH butyrate, lactate, glucose, free fatty acids and endogenous energy substrates. The balance of requirement changes in working muscle; the balance of lipid derivative use changes in favour of free fatty acids away from acetate, the use of β-OH butyrate and lactate remains relatively constant, endogenous energy substrate use declines and glucose use increases (Bird *et al*, 1981; Pethick, 1984). The most significant effect of exercise for lactation therefore would appear to be to cause a drain on the blood glucose pool.

The main demands for glucose are fourfold; for normal tissue respiration, lactose synthesis, growth and respiration of the concepta and increased muscle respiration. Under fed conditions, when glucose may be in surplus, glucose can be used to produce glycogen or can be converted to glycerol and fatty acids in body lipid stores. Under conditions of glucose deficit, glucose may be synthesised from glycogen, free fatty acids and amino acids. The use of these precursors are under hormonal control, mainly the anabolic hormone insulin and the hormones which inhibit tissue deposition (growth hormone, glucagon and glucocorticoides) (Oldham, 1985). It is possible that glucose supply itself (or glucose precursor supply) can also affect the utilisation of other metabolites (eg. free fatty acids) through its influence on insulin

levels (Sutton, 1980).

This suggestion is supported by the work of Miettinen, Huhtanen and Ala-Seppala (1988) who found that higher insulin concentrations resulted from barley rich diets, which they suggested might be related to higher glucose absorption in the small intestine. High barley diets also were associated with lower free fatty acid levels than other diets in the experiments (barley/molasses and unmollassed sugar beet pulp), which these authors considered indicated either decreased lipolysis or increased lipogenesis due to increased insulin levels. The effects of exercise on metabolite utilisation therefore, are superimposed on these already complex control mechanisms. In late pregnancy and late lactation, tissue catabolism occurs to support the growth of concepta rather than lactation. In early lactation, mobilised body tissue contains a high proportion of fat and a low proportion of amino acids. The catabolic metabolism of glucose is also minimised in early lactation (Oldham, 1985) and hypertrophy of the gut occurs. This is mirrored in late pregnancy by mammary development in anticipation of lactation. Maternal tissue amino acids may be mobilised in late pregnancy to meet these demands and those of the growing foetus.

Some authors (Lawrence, 1985; Krautforst, 1947; Rajapurohit, 1979) have asserted that in 'well fed animals' exercise has no effect on lactational performance. Tornede (1939) described the effect of work on milk production in Red Hill Cattle in Germany and considered that even the effects of very heavy work could be overcome by better feeding. The term 'well-fed' was not precisely defined by these authors, but it is assumed that this referred to

overall energy intake. One definition would be that 'well-fed' amounts to those conditions of feeding under which lactational performance is not influenced by exercise.

The diets used in the present experiments were designed to be isoenergetic, but to provide energy metabolites in different combinations and to provide different pathways for glucose production. In Experiments I and II animals were offered an amount of food which was calculated to provide ME requirements (excluding exercise) and the animals could be considered 'adequately-fed' in the non-walking periods, but less well-fed (in terms of ME) when walking. In Experiment III animals were offered a fixed amount of supplement to *ad libitum* straw and the energy intake was estimated to be below the requirement of the animals by up to 33MJ in the walking period. The animals in Experiment III could therefore be considered to be less well-fed than animals in the previous experiments.

In Experiment I all animals received the same high roughage diet, and milk yield decreased by 10.7 percent. In Experiment II animals which received a lower roughage/higher concentrate diet based on the same constituents as the diet in Experiment I, had a lower decline in milk yield when walking. The higher concentrate diet, which was likely to produce a greater propionate and lower acetate supply, was more able to sustain milk yield. In Experiment III the diet designed to provide greater amounts of glucose from either propionate or starch digested in the small intestine, again showed the lowest milk yield reduction after exercise. Even though the animals in Experiment III had *ad libitum* access to straw, they

were not able to eat enough to compensate for the extra energy demand of exercise. The diets in Experiment III were most similar to the diets of tropical animals in that poor quality roughage was a major component. The concentrate parts of the diet were of higher nutrient density than would be given to most tropical draught animals, but tropical animals may receive supplements of tree leaves, fresh grass, urea or grain millings.

In the present experiments, the supply of lipid precursors from the diet was not deliberatley manipulated and was unlikely to have been a significant determinant of milk yield. The animals used in the experiments were in relatively good condition and had body fat reserves. Milk fat yields were not significantly affected when animals walked and diets which were most likely to provide greater lipid supplies as a result of digestion were least able to maintain milk yield when the animals walked.

Energy supply *per se* appeared not to be as important a determinant of the response to exercise as the quantities and balance of individual nutrients supplied. 'Well-fed' draught cows can therefore be described as animals receiving diets which provide the right balance of energy metabolites. Diets which provide the most direct glucose precursors (propionate) appear better able to maintain milk yield in working or exercising animals than diets which predominantly provide amino acids or free fatty acids.

The findings of these experiments partly support the suggestions that in 'well-fed' animals, work has a smaller affect on milk yield than in animals on poorer diets. The results indicated that diet quality is important even when total ME is

sufficient to meet energy requirements. Exercise may be expected to affect milk yield either a) when ME is limiting or b) when ME is not limiting but the diet does not supply the correct proportions of metabolites.

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7.8. THE EFFECT OF EXERCISE ON BODY WEIGHT CHANGES

The analyses of blood constituent levels which showed increased blood concentrations of free fatty acids and β-OH butyrate when animals walked suggests that some tissue mobilisation occurred when the animals walked.

The mean differences in weight gain seen in each experiment were relatively small (approximately 10 percent of body weight), but were consistent between experiments.

The weight gain of the first non-walking groups in each experiment is assumed to represent normal growth for the particular diets and includes normal growth of concepta and tissue growth. There is also the possibility that gut-fill increased during the first experimental periods relative to gut-fill prior to the experiments when the animals were on a silage diet.

It is assumed that the rate of growth of concepta was not influenced by the experimental treatments. Average weights for concepta were calculated from ARC (1980) and predicted mean weight increases of concepta over the three week periods were 7.5kg (between day 176 and 197 of pregnancy) and 8.5kg (between day 197 and 218 of pregnanacy) for the non-walking and walking periods of Experiment I, compared with 4.5kg (between day 143 and 164), 6.5kg (between day 164 and 185) and 7.5kg (between day 185 and 206 of pregnancy) in Periods I, II and III in Experiment II.

In Experiments I, II and III respectively in the first non-walking groups, the mean body weight gains were 16Kg (AA6 ExI), 17Kg (AA6 ExII) and 13Kg (HS1 ExII) and 11.50Kg (HS2 ExIII), 0.33Kg

(DF ExIII) and 23.75Kg (HP ExIII) over each three week period for each diet treatment respectively. All of these gains (except for DF in Experiment III) are well in excess of the estimated growth of concepta.

The calculated energy balances of the animals in each experiment were largely consistent with the body weight changes observed in the animals. It is assumed that some tissue mobilisation occurred, but that this was largely masked by changes in gut-fill.

The weight changes recorded were similar to changes seen in other experiments using non-pregnant, non-lactating buffaloes (Ffoulkes, 1986; Winngroho, 1988), oxen (Astatke *et al*, 1986) and lactating cows (Barton, 1987b). These authors attributed changes to tissue gain or loss and did not discuss the possible effects on weight changes of changes in gut-fill and the rate of passage of digesta due to exercise.

In the present experiments in walking periods in each experiment the animals apparantly gained less than during the previous control periods. This lower rate of gain can be explained either by loss of body condition, dehydration or loss of gut-fill.

The energy demands made by walking (approximately 12MJ/d) would not account for the reduced weight gain and weight losses by tissue weight loss observed in the walking period. Similarly, the weight gains observed after exercise were too great to be explained by tissue weight gain or growth of concepta. In Experiment I condition as measured by condition score (Lowman, Scott and Somerville, 1976; Appendix 6A) did not change over the periods, but changes were

observed in Experiment III in which seven cows lost condition by the end on the third period Apendix 6C).

The animals had free access to water at all times (including during the walking period) and there is no reason to believe that they were less hydrated when walking than when not walking. Weighings were carried out at 10.00h and this would allow time since the previous day's walking for rehydration to occur. Hence it is assumed that the main influence on weight change was gut-fill.

Experiments I and II differed from Experiment III in that food intake was fixed to meet requirements. In the first two experiments animals always ate all the food offered, but could not compensate for an energy deficit by eating more. In Experiment III the animals received a fixed amount of supplement, but had *ad libitum* access to barley straw and had the opportunity to make-up energy deficits by eating more, if this was physically possible, and for increase in the rate of passage. If the rate of passage through the lower gut increased in these experiments, this would result in a net loss of digesta from the tract in the walking period relative to the previous period and the animals would apparently lose weight.

In Experiment I in Period I (three weeks) the first walking group (WC) gained 10Kg and the first control group (CW) gained 16Kg. It is assumed that the difference between the two represents loss of gut-fill due to an increased rate of passage. In Period II group WC gained 34Kg and group CW gained 12Kg. The rapid gain in Period II by group WC could be explained by the replacement of gut-fill after walking and could not be explained solely by tissue weight gain.

In Experiment II both groups in the first period gained weight at the same rate. In the walking period weight gains fell to zero in both groups and then increased again in Period III so that by the end of Period III, mean weights for each group were as expected based on period one growth rates. This recovery in weight loss after exercise was similar to that observed in Experiment I. This supports the assumption that the loss of weight in the walking period was due mainly to changes in gut-fill which were replaced in the subsequent non-walking period.

In Experiment III, in which more than half the dry-matter intake on each dietary treatment was roughage, the patterns of weight change did not follow those of the previous experiments. In comparison to Experiment II, none of the treatment groups managed to meet the expected weights based on extrapolation of the weight gains in the initial control. All groups however, showed more rapid weight gains in the control period following exercise, as observed in both previous experiments. Weight losses in the walking period were more pronounced than in previous experiments. This may indicate a greater effect of exercise on rate of passage in animals on high roughage diets.

Some previously reported evidence suggests that exercise or work can affect digestion or digestive functions (Ffoulkes, 1986; Winngroho, 1988), whereas other evidence suggests the contrary (Kibet and Hansen, 1985; Henning, 1987). Exercise may act as a physical stimulus to movement of digesta and may cause mixing of rumen and gut contents, which may aid the passage of digesta through the tract. In the present experiments voluntary intake of

straw decreased, though the animals may have eaten more of a better diet had they had the opportunity. This will be discussed in the next section.

7.9. THE EFFECT OF EXERCISE ON STRAW INTAKE

The results of the present experiments on the effect of exercise on voluntary food intake differ from those of other experiments carried out in Bangladesh (Barton, 1987b), Indonesia (Ffoulkes, 1986; Ffoulkes, Bamualim and Panggabean, 1987; Winngroho, 1988) and in South Africa (Henning, 1987). Barton found that work did not increase straw intake in working bullocks in Bangladesh, in agreement with Henning who exercised sheep on treadmills. Ffoulkes (1986), Ffoulkes *et al* (1987) and Winngroho (1988) however, found that work increased feed intake of course roughage (rice straw) and fresh grass. The results of the present experiment in which animals were observed to eat less poor quality roughage when they walked (though this effect was not statistically significant), contrasts with these results.

Ffoulkes *et al*, (1987) concluded from their work, in which walking buffaloes ate 7 percent more poor quality roughage and in which digestibility increased from 46.9 to 52.9 percent, that if these were true effects of exercise then the point at which tissue building nutrients are utilised as energy sources for prolonged muscular activity will be delayed by the greater availability of nutrients from the diet when animals exercise or work. These animals walked horizontally for three hours. This relatively light exercise may have a beneficial effect of digestive function by

causing greater mixing of the rumen contents, which may enhance microbial fermentation. At higher levels of work and exercise however, more detrimental effects may be seen. It might be expected for example, that higher work levels would cause a shift of blood supply from the gut to muscles and peripheral tissues.

The differences between the present results and those of previous authors might also be explained by the different diet types fed. In the present experiment the animals only had the opportunity to increase their intake of straw. In the experiments describe in which intake increased when animals worked, the animals also had *ad libitum* access to fresh grass as well as straw.

The time spent walking also may have resulted in the animals not having adequate time to eat. Henning (1987) considered that the time spent working did not interfere with feed intake in his experiments and cited evidence from grazing animals to support this supposition. Stall-fed animals eating poor quality roughage however, may respond differently to grazing animals.

Barton (1987b) found that animals which were given urea treated rice straw ate more than animals which were fed untreated straw, this being due to the increased digestibility of treated rice straw. The present results also indicate different effects of diet supplement. The high protein diet resulted in the greatest straw intake. This diet apparantly provided a greater supply of N to rumen microbes and of the three diets maximised rumen microbial function and straw breakdown. This contrasted to HS2 and DF supplements which supported lower straw intakes, presumably in proportion to the N content of the diets.

It is interesting to note that the diet which persistently produced the greatest straw intake (HP), did not produce the highest milk yield, which persistently was produced by cows receiving the high starch diet.

Levels of straw intake have been shown to be positively correlated with RDP intake (Alawa, Fishwick, Parkins and Hemingway, 1987). These authors demonstrated an increased intake of barley straw on a barley diet compared with a molassed sugar beet pulp diet, but not increased intake of ME because of lower digestion of straw on the barley supplement. Similarly, Fadel, Uden and Robinson (1987) have demonstrated that cows fed fishmeal supplements had increased neutral detergent fibre intakes and digestion compared with control cows and Oldham, Fulford and Napper (1981) found that DM digestibility was higher at higher levels of dietary crude protein intake. The present results support these earlier findings.

The present experiments, in which exercise decreased voluntary intake of poor quality roughage, therefore did not support the findings of previous work which showed positive effects on poor quality roughage intake.

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7.10. PARTITION OF ENERGY

In Experiment I, which had a cross-over design, animals were largely in positive energy balance. These animals showed the most favourable balances of animals in any experiment. In the first period the non-walking group was in positive balance by 7.4MJ whereas the walking group were in slight negative balance (2.3MJ). Both groups gained weight however, by means of 0.8 and 0.5kg/d. Three weeks later in the second period when milk yields were lower, both the walking and non-walking groups were in positive balance by 4.1MJ and 6.8MJ respectively. Again, both groups gained weight (0.6 and 1.6kg/d for walking and non-walking groups respectively).

The positive energy balances in the second period would be expected, since the ration allowance was based on energy requirements at the beginning of the first period. The requirement three weeks later differed according to the level of decline of milk yield and the increased demand for growth of concepta. In this case the decreased demand for lactation appears to be greater than the increased demand for growth of concepta. The positive balance in the first non-walking group can best be explained by an over estimation of the requirement or a greater energy content of the ration than estimated (ie. greater than 10.39MJ/kgDM). No allowance was made for body weight gain and if tissue growth was occurring, this would indicate a larger over-estimation of allowance.

The observation of body weight increase in animals which were apparantly in negative energy balance is more difficult to explain. If the assumptions made and the data upon which the balances were

calculated were largely correct, then the apparant contradictions can be explained in a number of ways. Firstly animals were pregnant and, while not being very energy demanding, the weight increase of concepta may have been significant. Secondly the weight increases may have included some increase in gut fill, particularly in the non-walking periods. Thirdly, when animals exercise, they may lose adipose tissue, but gain lean tissue and rather than losing overall body weight may maintain weight or grow.

In Experiment II there were no inconsistencies between energy balance and body weight changes. In the first non-walking period animals were in slight positive energy balance (2.7MJ for animals fed diet AA6 and 2.1MJ for animals fed diet HS1) and gained weight (0.7kg/d for animals fed diet AA6 and 0.6kg/d for animals fed diet HS1). Similarly, in the second non-walking period, animals were in greater positive energy balance and gained more weight. In the intervening walking period animals were in negative energy balance (3.1 and 3.9MJ respectively for each diet) and lost weight (0.4 kg/d for animals fed diet AA6 and 0.2 kg/d for animals fed diet HS1).

In Experiment III animals fed each diet were in negative energy balance in all three periods. The only weight losses however, were in the walking period. In the first non-walking period the animals were in deficits of between 20 and 26MJ/d, but gained up to 1.1kg/d depending on the dietary treatment. In the second non-walking period animals were in deficits of between 10 and 16MJ/d and gained up to 1.6kg/d. Energy deficits increased to between 26 and 33 MJ/d in the walking period when weight losses were between 0.2 and

0.5kg/d.

The energy deficits caused by exercise in the present experiments may be similar to the effects caused by fasting. For example, the blood metabolite changes recorded earlier were similar to levels recorded by Baird (1977) for starved, ketotic animals.

7.11. ESTIMATIONS OF METABOLITE SUPPLY

It is clear from the calculations made of metabolite supply that each diet provided metabolites in different proportions. The calculated supplies of propionate, amino acids and pre-caecally digested starch from each diet in the first non-walking period are summarised in Table 7.1 (see Tables 6.9 to 6.14 for details).

Table 7.1. Calculated supply of propionate, amino acids and starch from each diet in each experiment in the first non-walking period

Experiment	I	II	II	III	III	III
Diet	AA6	AA6	HS1	HS2	DF	HP
Propionate (moles/d)	15.3	17.5	20.1	8.6	12.8	9.2
Total Metabolisable Protein Supply (g)	835.8	972.8	930.7	493.6	456.6	1015.7
Starch (g)	140.2	160.6	171.0	396.6	60.3	35.2

The accuracy of these estimations depends upon the assumptions outlined in Chapter Six. The calculations were made using estimates of metabolite supply from the current literature, but broad margins

of error may be attached to the estimates. The estimations provide a basis for judging the ability of different diets to provide glucose, and in this sense are a means of determining the best type of diet to feed tropical draught cows. In practical terms, the final judgement about the appropriateness of such diets must be made from first hand experience of the performance of animals under field conditions.

The proportion of glucose requirements which could potentially be met from propionate were 86.5% (AA6 ExI), 91.1% (AA6 ExII), 96.3% (HS1 ExII), 53.9% (HS2 ExIII), 63.2% (DF ExIII) and 61.3% (HP ExIII). This demonstrates the differential ability of the rumen to produce glucose precursors depending on the diet quality and emphasises the need to maximise rumen fermentation in order to meet glucose requirements from propionate. Previous estimates have put the proportion of glucose derived from propionate at 60 percent (Wiltrout and Satter, 1972) and it has been assumed that glucogenesis from amino acids made up the remainder (Black, Egan, Anand and CXhapman, 1969; Trenkle, 1980). If it is true however, that the contributiuon of amino acids is lower than this, as suggested by Oldham and Smith (1982), then the contribution of propionate may be higher.

It is noticeable that some diets (AA6 and HS1) were able to meet glucose requirements from the products of rumen fermentation (ie. propionate and rumen degradable protein) with only little support for glucose production from undegradable protein supplies or duodenally digested starch. The diets fed in Experiment III however, contrasted strongly with the diets of the first two

experiments and all three diets relied heavily on amino acids and starch as sources of glucose.

It is apparent that diets which encourage a greater proportion of digestion to occur post-ruminally, not only reduce the overall contribution of the rumen to digestion, but also influence the ratio of volatile fatty acids produced in the rumen, with a tendency to produce a smaller proportion of propionate.

In the first non-walking period diets AA6 and HS1 were able to provide excess supplies of glucose to requirements. This finding agrees with the results of the energy balance calculations which were positve in the first non-walking periods and in which animals gained weight. Diet HS2 (high starch based on maize) was not able to meet the glucose requirement of cows fed this diet and similarly, diet HP was unable to meet the requirement in the first non-walking period.

When animals began to walk the demand for glucose for lactose production and the demand for amino acids for body growth decreased, since all animals produced less milk and either grew more slowly of lost body weight. The glucose demand for walking has not been calculated, but the glucose balances calculated for the walking period (Appendix 8C) indicate that animals in Experiment III were less well prepared to meet the extra glucose demands of walking than were animals fed diets AA6 and HS1 in Experiments I and II.

7.12. IMPLICATIONS FOR THE MANAGEMENT OF TROPICAL DRAUGHT COWS

7.12.1. PREFERRED DIETS FOR WORKING COWS

The results of the experiments carried-out in the research programme provide some information on which to base practical rations for working cows in the tropics. The preferred diet for tropical draught cows is one which will provide high levels of propionate. This can be achieved by maximising the level of rumen fermentation and providing supplementation which will be digested in the rumen. Tropical diets almost invariably include large amonts of roughage. This is often poor quality roughage such as rice straw and mature herbage. Such diets would be expected to produce high levels of acetate and lower levels of propionate than preferred.

If roughage is to be a major component of the diet, the first objective should be to provide roughage of the highest possible quality. Fresh herbage should be young and leafy so as to provide relatively high levels of crude protein to support rumen fermentation. Older vegetation has lower levels of crude protein and would probably require a source of nitrogen supplementation.

A second possibility would be to treat straw with alkali (sodium or ammonium hydroxide). The present experiments did not use diets which incorporated treated straw, but the results of Barton's work (Barton, 1987b) indicate that nitrogen-enriched treated straw is better able to maintain milk yield than non-treated straw. This will result from increased digestibility brought about by treatment and the additional nitrogen available to microbes if urea treatment is used. Roughage diets should be supplemented with green

vegetation. Browse and tree leaves have high crude protein levels and would be an appropriate supplement to poor quality roughage.

Uncooked ground maize has been shown to be a less than ideal concentrate in the present experiments, but grains such as sorghum and millet might be more appropriate. Flaked maize is more fermentable. Feeding such grains to ruminant animals however, might compete with human beings. Grain offals are often available for ruminants, and these offer low levels of appropriate suplementation. Concentrates such as cottonseed cake provide high levels of amino acids, which have a high undegradable proportion.

High energy supplements such as molasses which encourage rumen fermentation would be appropriate for draught cow diets. If fed with urea, this will ensure better utilisation of the available energy. Urea is a source of fermentable nitrogen which contributes exclusively to microbial protein production. Other fermentable energy sources such as bananas might also be considered.

7.12.2. DRAUGHT COW MANAGEMENT

Although it has been demonstrated that milk yield is adversely effected by walking and that in animals which are ploughing the effect is likely to be up to twice that observed in the present experiments, it has also been established that milk yield can recover on resting days. It was noted that recovery was not complete after one resting day, but that two resting days were required for complete, or almost complete, recovery of milk yield to pre-walking levels. Hence it would be recommended that farmers

should rest animals for two full days every four or five days. It is recognised that this might not be a practical proposition for farmers who have high cultivation demands over short periods. Cows used for pulling carts, however, could be provided more easily with the optimum number of resting days.

The animals used in the present experiments were all pregnant and were exercised as late as day 240 of pregnancy (Appendix 2). Animals were not apparently stressed by the level of exercise carried out in the present experiments, but heavier work might not be advisable after month seven of pregnancy.

It is likely that in many tropical farming systems, cows would be required to work in late pregnancy or early lactation, since the planting season (early rains) usually coincides with peak calving patterns in seasonal rainfall areas. It would be advantageous to time the breeding season so that calving occurs at the end of the dry season. This might also be recommended in terms of calf management, since calves born in the early wet season may suffer from chills due to heavy rain. Such cows would be working during early lactation, when the effect of the extra energy requirement for work may have a larger effect on lactational performance than demonstrated in the present experiments. The diets of such animals would require close attention. Supplementation with concentrates available would be appropriate for such animals at this time.

Using cows for work in early lactation might affect fertility levels and cause prolonged calving to conception intervals. The solution to this also lies partly in proper feeding management.

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CONCLUSIONS

The present work has quantified the effect of a fixed amount of exercise on milk yield and milk constituent content and yield in pregnant cows reared under temperate conditions and offered a range of diets. The research has provided information about the effect of exercise on blood metabolite changes, body weight changes and straw intake and has allowed speculation about dietary effects on the lactational response to exercise.

Cows are used as draught animals in many parts of the world and evidence suggests that their use for draught power production will increase. The results of the present work make a contribution to the establishment of guidelines for the feeding of draught cows under tropical conditions.

The research has shown that if cows are used for work there is likely to be a short term reduction in milk yield, possibly irrespective of initial level of milk yield. Such a reduction is associated with a reduction in milk protein and lactose yield, but not necessarily with a reduction in milk fat yield. If animals are managed well and are given adequate rest days, the yield is likely to return to pre-work levels after work ceases. The 'rule-of-thumb' that better fed animals are less affected by work than less well-fed animals, would appear to have some justification, particulaly at low levels of milk production. It is not only the total energy intake which is important, but also the quality of the diet and the type of metabolites produced.

The present work has quantified the effects of exercise on lactational performance under controlled experimental conditions. It would be appropriate for similar detailed study to be carried out under tropical conditions with adapted tropical animals doing farm-work such as ploughing and carting loads. This would allow the effect of high ambient temperatures to be taken into account.

Of first priority is the need to determine the best tropical animal feeds to support lactation in working cows. Since draught cows provide many products, including progeny for replacements and meat production, milk and draught power, better feeding is easily justified. The investment by farmers in better food for their draught cows will see returns to both their livestock and crop production enterprises.

It is likely that the levels of milk production obtained by tropical draught cows will be similar or lower than the levels of production measured in the cows in the present experiments. Hence, research in lower yielding animals would be appropriate. In addition, the effects of work on milk yield in early lactation in non-pregnant cows deserves attention.

Related to the need to determine appropriate foods for tropical draught cows, is the effect that work has on voluntary food intake. The results of the present experiments have not confirmed previous research, and more detailed research is required.

Uncertainty still exists about effects of exercise on digestion and rate of passage. These factors may also affect the nutrient supply of the diet, particularly if an effect of exercise is to help mix the rumen contents. More detailed measurements are

required of levels of rumen fermentation, volatile fatty acid concentrations and metabolite uptake in working cows.

No measurements were made in the present experiments of changes in body fat to lean tissue or of total body water changes during exercise. A more detailed investigation of such changes would be appropriate.

The effects of work on fertility have received little attention. Since fertility is partly related to the energy status of the animal, the type of reseach suggested above to determine optimum feeding standards for draught cows should also be seen in this broader context. In particular, the effects of changes in blood metabolite concentrations (particularly glucose) in relation to aspects of reproductive physiology should be investigated.

The animals in the present experiments showed some weight loss, and the negative energy balances associated with this weight loss may also affect nutrient supply to the growing foetus. The effect of sustained work on birth weight is not known.

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REFERENCES

REFERENCES

Agarwal, S.P., Singh, N., Agarwal, V.K. and Dwaraknath, P.K. (1982) Effects of exercise on serum electrolytes and their relationship in entire, castrated and vasectomised male bufffaloes. **Indian Vet. J.,** *59:*181-184.

Ahmed, A. (1978) Livestock in Bangladesh: Their present status and development strategy. **Asian Livestock,** *3(8):* 6 8.

Akhtar, A.S. (1981) Draught animal power as a source of renewable energy in Pakistan. **Asian Livestock,** *6(2):* 13.

Allison, C.D. (1985) Factors affecting forage intake by range ruminants: A review. **J. Range Man.,** *38(4):* 305-311.

Anderson, M.J., Lamb, R.C., McKelson, C.H., Blake, J.T., Olsen, J.D. and Arave, C.W. (1977) Facility for Exercising Dairy Cows. **J. Dairy Sci.,** *60(7):* 1173-1175.

Alawa, J.P., Fishwick, G., Parkins, J.J. and Hemingway, R.G. (1987) A note on the effects of dietary protein degradability in the rumen on the voluntary intake and digestibility of barley straw by lactating beef cows. **Anim. Prod.,** *44:* 446-449.

Annison, E.F. (1965) Absorption from the ruminant stomach. 2nd International Symposium on the Physiology of Digestion in the Ruminant. p. 185-197. Butterworth, London and Washington.

Annison, E.F. (1984) The metabolism of neutral and acidic lipids by tissues of the ruminant. In: Gilchrist, F.M.C. and Mackie, R.I. (Eds) Herbivore Nutrition in the subtropics and tropics, pp. 549-570. Science Press, S. Africa.

Annison, E.F. and Armstrong, D.G. (1970) Volatile fatty acid metabolism. In: A.T. Phillipson (Ed) Physiology of Digestoin and Metabolism in the ruminant, pp. 422-437. Newcastle-Upon-Tyne, Oriel Press.

Annison, E.F. and Linzell, J.L. (1964) The oxidation and utilisation of glucose and acetate by the mammary gland of the goat in relation to their overall metabolism and to milk formation. **J. Physiol. (London),** *175:* 372-385.

Annison, E.F. and White, R.R. (1962) Further studies on the entry rates of acetates and glucose in sheep, with special reference to endogenous produciton of acetate. **Biochem. J.,** *84:* 546-552.

Annison, E.F., Bickerstaffe, R. and Linzell, J.L. (1974) Glucose and fatty acid metabolism in cows producing milk of low fat contents. **J. Agric. Sci., Camb.,** ***82:*** 87-95.

Annison, E.F., Lindsay, D.B. and White, R.R. (1963) Metabolic interrelations of glucose and lactate in sheep. **Biochem J,** ***88:*** 243-248.

Annison, E.F., Linzell, J.L., West, C.E. (1968) Mammary and whole animal metabolism of glucose and fatty acids in fasting lactating goats. **J. Physiol. (London),** ***197:*** 445-457.

Anon (1949) The Use of Cows for Work. **Indian Farming.,** ***10:*** 286-287.

Anon (1978) Livestock production in S.Korea. **Asian Livestock,** ***3(1):*** 8-13.

ARC (1980) The nutrient requirements of ruminant livestock. Agricultural Research Council/Commonwealth Agricultural Bureaux, Farnham Royal.

ARC (1984) The nutrient requirements of ruminant livestock. Supplement No. 1. Agricultural Research Council/Commonwealth Agricultural Bureaux, Farnham Royal.

Armstrong, D.G. (1965) Carbohydrate metabolism in ruminants and energy supply. In: Physiology and Digestion in Ruminants. (Ed. Dougherty, R.W.) pp. 272-288. Butterworths, Washington.

Astatke, A., Reed, J.D. and Butterworth, M.H. (1986) The effect of diet restriction on work performance and weight loss of local Zebu and Friesian x Boran crossbred oxen. ILCA Bulletin 23, International Livestock Centre for Africa, Addis Ababa.

Attebery, J.T. and Johnson, H.D. (1969) Effects of environmental temperature , controlled feeding and fasting on rumen motility. **J. Anim. Sci.,** ***29:*** 734-737.

Baird, G.D. (1977) Aspects of ruminant intermediary metabolism in relation to ketosis. **Biochem. Soc. Trans.,** ***5:*** 819-827.

Baird, G.D., Hibbit, K.G., Hunter, G.D., Lund, P., Stubbs, M. and Krebs, H.A. (1968) Biochemical aspects of bovine ketosis. **Biochem. J.,** ***107:*** 683-689.

Baird, G.D., Symonds, H.W. and Ash, R. (1975) Some observations on metabolite production and utilisation *in vivo* by the gut and liver of adult dairy cows. **J. Agric. Sci. Camb.,** ***85:*** 281.296.

Balch, C.C. and Campling, R.C. (1962) Regulation of Voluntary food intake in ruminants. **Nut. Abst. Rev.,** ***32:*** 669-686.

Ballard, F.J., Hanson, R.W. and Kronfeld, D.S. (1969) Gluconeogensis and lipogenesis in tissue from ruminant and non-ruminant animals. **Fed. Proc. Fed. Am. Soc. Exp. Biol.,** *28:*218-231.

Balmain, J.H., Folley, S.J. and Glascock, R.F. (1954) Relative utilisation of glucose and acetate carbon for lipogenesis by mammary gland slices, studies with tritium 13_c and 14_c. **Biochem. J.,** *56:* 234-239.

Bartlett, J. and Gibbon, D. (1984) Animal Draught Technology: An annotated bibliography. Overseas Development Group, University of East Anglia.

Barton, D. (1987a) Draught Animal Power in Bangladesh. Ph.D. Thesis, University of East Anglia.

Barton, D. (1987b) Draught power supply, nutrition and the work output of draught animals in Bangladesh. A Report prepared for the Ford Foundation, Dhaka.

Beever, D.E., Coehlo Da silva, J.F. and Armstrong, D.G. (1970) The effect of processing maize on its digestion in sheep. **Proc. Nutr. Soc.,** *29:* Abs. 43A.

Bell, A.W. and Hales, J.R.S. (1985) Conflicting requirements of exercise and heat stress for blood flow distribution in domestic animals. In: Copland, J.W. (Ed) Draught Animal Power for Production. ACIAR Proceedings Series 10. James Cook University.

Bergman, E.N. (1973) Glucose metabolism in ruminants as related to hypoglycaemia and ketosis. **Cornell Vet.,** *63:* 341-382.

Bergman, E.N., Roe, W.E. and Kon, K. (1966) Quantitative aspects of propionate metabolism and gluconeogenesis in sheep. **Am. J. Physiol.,** *211:* 793-799.

Bergman, E.N., Starr, D.J. and Reulein, S.S. (1968) Glycerol metabolism and gluconcogensis in the normal and hypoglycaemic ketotic sheep. **Am. J. Physiol.,** *215:* 874-880.

Bergman, E.N. and Wolff, J.E. (1971) Metabolism of volatile fatty acids by liver and portal-drained viscera in sheep. **Am J. Physiol.,** *221:* 586-592.

Bickerstaffe, R., Noakes, D.E. and Annison, E.F. (1972) Quantitative aspects of fatty acid biohydrogenation, absorption and transfer into milk fat in the lactating goat, with special reference to the cis-and trans-isomers of octadecenoate and linoleate. **Biochem. J.,** *130:* 607-617.

Bickerstaffe, R., Annison, E.F. and Linzell, J.L. (1974) The metabolism of glucose, acetate, lipids and amino acids in lactating dairy cows. **J. Agric. Sci., Camb.,** *82:* 71-85.

Bines, J.A. and Hart, I.C. (1982) Metabolic limits to milk production, especially roles of growth hormone and insulin. **J.Dairy Sci., 65: 1375-1389.**

Bird, A.R., Chandler, K.D. and Bell, A.W. (1981) Effects of exercise and plane of nutrition on nutrient utilisation by the hind limb of sheep. **Aust. J. Biol. Sci.,** ***34:*** 541-550.

Black, A.L., Egan, A.R., Anand, R.S. and Chapman, T.E. (1968) The role of amino acids in gluconeogenesis in lactating ruminants. In: Isotope studies on the nitrogen chain. **Int. Atomic Energy Agency, Vienna, pp. 247-263.**

Borensztajn, J. and Robinson, D.S. (1970) The effect of fasting on the utilisation of chylomicron triglyceride fatty acids in relation to clearing factor lipase (lipo protein lipase) releasable by heparin in the perfused rat heart. **J. Lipid Research,** ***11:*** 111-117.

Bruckental, I, Oldham, J.D. and Sutton, J.D. (1980) Glucose and urea kinetics in cows in early lactation. **Br.J.Nutr.,** ***44:*** 33-45.

Brockman, R.P. (1978) Roles of glucagon and insulin in the regulation of metabolism in ruminants: a review. **Can. Vet. J.,** ***19:*** 55-62.

B.S.I. (1969) Gerber method for the determination of fat in milk and milk products. British Standards Institute. BS696: Part II, Methods.

Buckley, B.A., Herbein, J.H. and Young, J.W. (1982) Glucose kinetics in lactation and non-lactating dairy goats. **J. Dairy Sci.,** ***65:*** 371.

Bunyavejchewin, P., Veerasit, P., Chaidirek, P. and Chantalakhana, C. (1985) Changes in body temperature and working efficiency of Thai Swamp Buffaloes. In: Copland, J.W. (Ed) Draught animal power for production. ACIAR Proceedings Series 10. James Cook University.

Buranamanos, P. (1963) A survey of buffaloes in Thailand. Faculty of Veterinary Science, Kasetsart University, Bangkok.

Cakala, S. (1965) Effects of high temperature on reticulo-ruminal motility in goats. **Bull.Vet.Inst.Pulawy.,** ***9:*** 103-

Chandler, K.D. and Bell, A.W. (1981) Effects of maternal exercise on foetal and maternal respiration and nutrient metabolism in pregnant ewes. **J. Dev. Phys.,** ***3:*** 161-176.

Chantalakhana, C. (1981) A Scope for Buffalo Breeding for Draught. In: Recent advances in buffalo research and development. Food and Fertiliser Centre, Taiwan.

Codazza, D., Maffeo, G. and Redaelli, G. (1974) Serum enzyme changes and haemato-chemical levels in thoroughbreds after transport and exercise. **J. S. Af. Vet. Ass.**, *45*: 331-334.

Collins, J. D. and Kelley, W. R. (1977) The haematology and clinical biochemistry of domesticated animals: the use of the international (SI) system of units. **Irish Vet. J.**, *31:* 127-133.

Cori, C. F. and Cori, G. T. (1928a, b and c) The mechanism of epinephrine action:

I. The influence of epinephrine on the carbohydrate metabolism of fasting rats, with a note on new formation of carbohydrates. **J. Biol. Chem.**, *79*: 309-319.

II. The influence of epinephrine and insulin on the carbohydrate metabolism of rats in the postabsorptive state. **J. Biol. Chem.**, *79*: 320-341.

III. The influence of epinephrine on the utilisation of absorbed glucose. **J. Biol. Chem.**, *79*: 343-355.

Cowan, R. T., Robinson, J. J., McHattie, I. and Pennie, K. (1981) Effects of protein concentration in the diet on milk yield, change in body composition and the efficiency of utilisation of body tissues for milk production in ewes. **Anim. Prod.**, *33:* 111-120.

Davis, S. R. and Collier, R. S. (1985) Mammary blood flow and the regulation of substrate supply for milk synthesis. **J. Dairy Sci.**, *68*: 1041-1058.

Dolberg, F. (1981) Rural versus urban benefits from cattle production, feed resource utilisation, the role of cattle and their farming systems. pp. 430-455, Second seminar on maximum production from minimum land, Bangladesh Agricultural University, Mymemsingh.

Duren, S. E., Jackson, S. G., Baker, J. P., Aaron, D. K. (1987) Effect of dietary fat on blood parameters in exercised thoroughbred horses. In: Gillespie, J. R. and Robinson, N. E. (Editors). Equine Exercise Physiology, Vol. II. ICEEP Publications, Davis, California.

Ellenberger, H. B. and Schneider, B. H. (1927) Exercise as a factor in digestion trials with dairy cows. Vermont Agr. Exp. Sta. Bull. 262.

Egan, A. R. and Black, A. L. (1968) Glutamic acid metabolism in the lactating cow. **J. Nutr.**, *96:* 450-460.

ESCA (1982) Nutrient allowances for cattle and sheep. Interim publication for College Staff only. East Scotland College of Agriculture, Scotland.

F.A.O. (1972) Manual on the employment of draught animals in agriculture. Food and Agriculture Organisation, Rome.

Fadel, J.G., Uden, P. and Robinson, P.H. (1987) Effect of nitrogen and energy supplements on intake and digestion of oat straw by non-lacting dairy cows. **J. Agric. Sci. (Camb.), *109:*** 503-511.

Ffoulkes, D. (1986) Studies on working Buffalo - current research on nutritional aspects. Balai Penelitian Ternakliawi, Bogor. **Draught Animal News, *6,*** CTVM, University of Edinburgh.

Ffoulkes, D., Bamualim, A. and Panggabean, T. (1987) Utilisation of fibrous feeds by working buffaloes. In: The Utilisation of fibrous agricultural residues as animal feeds. Ed. R. Dixon. Melbourne, University of Melbourne Printing Service.

Forbes, J.M. (1983) Models for the prediction of food intake and energy balance in dairy cows. **Liv. Prod. Sci., *10:*** 149-157.

Forsberg, N.E., Baldwin, R.L. and Smith, N.E. (1985) Roles of glucose and its interactions with acetate in maintenance and biosynthesis in bovine mammary tissue. **J. Dairy Sci., *68:*** 2544-2549.

Ganovski, K.H. (1984) Effect of movement on the digestibility of the diet and reproduction of pregnant cows. **Veterinarnomeditsinski Nauki, *21*:** 98.

Georgie, G.C., Sastry, N.S.R. and Razdan, M.N. (1970) Studies on the work performance of crossbred cattle. II Some physical and chemical responses of blood. **Indian J. Anim. Prod., *1*:** 115-119.

Gill, G.J. (1981) Farm Power in Bangladesh. Dev. Study 20. Vol I, University of Reading, Department Agricultural Economics and Management, Reading.

Gill, M., Siddons, R.C., Beever, D.E. and Rowe, J.B. (1986) Metabolism of lactic acid isomers in the rumen of silage-fed sheep. **Brit. J. Nutr., *55:*** 399-407.

Girdler, C.P., Thomas, P.C. and Chamberlain, D.G. (1986) Exogenous supply of glucose precursors and nitrogen utilisation in sheep. Abs. 43A. **Proc. Nutr. Soc., *45.***

Goe, M.R. (1983) Current status of research on animal traction. **World Animal Review, *45*:** 2-17.

Goldberg, G.R., Murgatroyd, P.R., Davis, H.L. and Prentice, A.M. (1988) **Proceedings of the Nutrition Society** Presented in December 1988.

Gollnick, P.D. (1985) Metabolism of substrates: energy substrate metabolism during exercise and as modified by training. **Fed. Proc., *44,*** 333.

Gonzalez, J.J., Robinson, J.J., McHattie, I. and Fraser, C. (1982) The effect in ewes of source and level of dietary protein on milk yield, and the relationship between the intestinal supply of non-ammonia nitrogen and the production of milk protein. **Anim. Prod.**, ***34:*** 31-34.

Gryseels, G. and Anderson, F.M. (1983) Research on farm and livestock productivity in the Central Ethiopian Highlands: Initial results, 1977 - 1980. ILCA Research Report. 4., ILCA, Addia Ababa.

Guzman, M.R. de and Perez, C.B. (1981) Feeding and Management Practices, Physical Characteristics and Uses of Carabaos (Swamp Buffaloes) in the Philippines. In: Recent advances in buffalo research and development. Food and Fertiliser centre, Taiwan.

Hadjipieris, G. and Holmes, W. (1966) Studies on feed intake and feed utilisation by sheep I. The voluntary feed intake of dry, pregnant and lactating ewes. **J. Agric. Sci. Camb.**, ***66:*** 217-223.

Harbers, F. (1981) Investigations on Parturition and Past Partum Morbidity and Mortality in Calves in the Thai Swamp Buffalo. In: Recent advances in buffalo research and development. Food and Fertiliser centre, Taiwan.

Hardwick, D.C. Linzell, J.L. and Price, S.M. (1961) The effect of glucose and acetate on milk secretion by the perfused goat udder. **Biochem. J.**, ***80:*** 37-45.

Hardwick, D.C., Linzell, J.L. and Mepham, T.B. (1963) The metabolism of acetate and glucose by the isolated perfosed uddedr. 2. The contribution of acetate and glucose to CO_2 and milk constituents. **Biochem. J.**, ***88:*** 213-220.

Harfoot, C.G. (1981) Lipid Metabolism in the Rumen. In: Lipid Metabolism in Ruminant Animals. Ed. W.W. Christie. Pergamon Press, Oxford.

Hays, F.L., Bianca, W. and Naf, F. (1978) Effects of exercise in young and adult cattle at low and high altitude. **Int. J. Biometeorology,** ***22:*** 147-158.

Henning, P.H. (1987) The effect of increased energy demand through walking exercise on intake and ruminal characteristics of sheep fed a roughage diet. **J. Agric. Sci. Camb.**, ***109:*** 53-59.

Hume, I.D., Jacobson, D.R. and Mitchell, G.E. (1972) Quantitative studies on amino acid absorption in sheep. **J.Nutr.**, ***102:*** 495-506.

Hunter, G.D. and Millson, G.C. (1964) Gluconeogenesis in the lactating dairy cow. **Res. Vet. Sci.**, ***5:*** 1-6.

Hutton, J.B. (1963) The effect of lactation on intake in the dairy cow. **Proc. New Zealand Soc. Anim. Prod.**, ***24:*** 29-42.

Hodgson, J. and Wilkinson, J.M. (1967) The relationship between liveweight and herbage intake in grazing cattle. **Anim. Prod.**, *9:* 365-376,

Ingjer, F. (1979) Effects of endurance training on muscle fibre ATP-ase activity, capillary supply and mitochondrial content in man. **J. Physiol.**, *294:* 419-432.

Jabbar, M.A. (1980) Draught power shortage and mechanisation of tillage in Bangladesh. **Bengal Journal of Agricultural Economics** 3: 1 - 26.

Jarrett, I.G., Filsell, O.H. and Ballard, F.J. (1976) Utilisation of oxidisable substrates by the sheep hind limb: Effects of starvation and exercise. **Metabolism,** *25:* 523-531.

Johnson, H.D. (1965) Environmental temperature and lactation (with special reference to cattle): a review. **Int. J. Biometeorology.** *9*: 103-116.

Johnson, H.D., Wayman, O., Kibler, H.H., Ragsdale, A.C., Berry, I.L. and Merilan, C.P. (1961) Effects of temperature and controlled feeding on milk production and related physiological reactions in cattle. **J. Anim. Sci.**, *20*: 974.

Kaufman, C.F. and Bergman, E.N. (1974) Renal ketone body metabolism and gluconeogenesis in normal and hypoglycaemic sheep. **Am. J. Physiol.**, *226:* 827-832.

Kelley, R.O., Martz, F.A. and Johnson, H.D. (1967) Effect of environmental temperature on ruminal volatile fatty acid levels with controlled feed intake. **J. Dairy Sci.**, *50:* 531-533.

Kibet, P.K.F. and Hansen, R.M. (1985) Effect of walking while grazing on rumen digestion. **East African Agricultural and Forestry Journal,** *51*: 30-35.

Kibria, Q.C. (1982) Draught Animal Power for Crop Production and Use of Cows. Maximum Production from Minimum Land. Proceedings of the 3rd Seminar held in Bangladesh, Mymensyngh.

Kőnig, B.A. (1982) The effects of stage of lactation and protein supply on metabolite turnover in dairy cows. Ph.D. Thesis University of Reading.

Krautforst, J.W. (1947) Influence of work balanced by food on the efficiency of cows. Animals Breeding Abstracts *16*: 115. 1948

Kumaratileke, W.L.J.S. and Buvanendran, V. (1979) A survey of production characteristics of indigenous buffaloes in Sri Lanka. **Ceylon Veterinary Journal,** *27*: 10 - 13.

Lawrence, P.R. (1985a) Work and milk production. Draught Animal News 4. p7. CTVM, University of Edinburgh, Scotland.

Lawrence, P.R. (1985b) A review of the nutrient requirements of draught oxen. ACIAR Proceedings No. 10. Ed. W.W.Copland, James Cook University, Queensland.

Lawrence, P.R. and Mathers, J.C. (unpublished) The work output and nutritional requirements of draught animals. Centre for Tropical Veterinary Medicine, Edinburgh.

Lawrence, P.R. and Richards, J.I. (1980) The energy cost of walking in some tropical draught animals. **Anim. Prod.**, *30:* 455.

Lawrence, P.R., Buck, S.F. and Campbell, I. (1989) The metabolic rate of oxen after work. **Abstract presented at the Winter Meeting of the BSAP 1989.**

Leng, R.A. (1970) Glucose synthesis in ruminants. **Advances in Vet. Sci.**, *14*: 209-260.

Leng, R.A. (1985) Muscle metabolism and nutrition in working ruminants. In: Draft power for production. ACIAR Proceedings No. 10 pp. 69-77. Ed. W.W. Copland, James Cook University, Queensland.

Leng, R.A., Steel, J.W. and Luick, J.R.C. (1967) Contribution of propionate to glucose synthesis in sheep. **Biochem J.**, *103:* 785-790.

Leng, R.A. and West, C.E. (1969) Contribution of acetate, butyrate, palmitate, stearate and oleate to ketone body synthesis in sheep. **Res. Vet. Sci.**, *10:* 57-63.

Lhoste, P. (1983) Developpment de la traction animale et evolution des systemes pastoraux au Sine Saloum, Senegal (1970 - 80). **Rev. Elev. Med. Vet. Pays. Trop.**, *36*: 291 - 300.

Lindsay, D.B. (1959) The significance of carbohydrate in ruminant metabolism. **Vet. Reviews and Annotations,** *5:* 103-128.

Lindsay, D.B. (1970) Carbohydrate metabolism in ruminants. In: Physiology of digestion and metabolism in; the ruminant. (ed. Phillipson, A.T.) pp. 438-451. Oriel Press, Newcastle.

Lindsay, D.B. (1978) Gluconeogenesis in ruminants. **Biochem. Reviews.** *6*: 1152-1156.

Lindsay, D.B. (1989) Gluconeogenesis in ruminants. **Biochem. Soc. Trans.**, *6:* 1152-1156.

Linzell, J.L. (1968) The magnitude and mechanisms of the uptake of milk precusors by the mammary gland. **Proc. Nutr. Soc.**, *27:* 44-52.

Lowman, B.G., Scott, N.A. and Somerville, S.H. (1976) Condition scoring of cattle. East Scotland College Agriculture, Scotland.

M. A. F. F. (1975) Energy allowances and feeding systems for ruminants. Technical Bulletin, 33, Ministry of Agriculture, Fisheries and Food, H. M. S. O., London.

Mann, S. O. and Orskov, E. R. (1973) The effect of rumen and post-rumen feeding of carbohydrates on the caecal microflora of sheep. **J. Appl. Bacteriol.,** ***36:*** 475-484.

McDonald, I., Edwards, R. A. and Greenhalgh, J. F. D (1980) Animal Nutrition. Longman.

Mepham, T. B. and Linzell, J. L. (1967) Urea formation by the lacting goat mammary gland. **Nature Lond.,** ***214:*** 507-508.

Mettrick, H. M. and James, D. P. (1981) Farm Power in Bangladesh, Volume II. Development Study, Department of Agriculture, University of Reading.

Miettinen, H., Huhtanen, P. and Ala-Seppala, H. (1988) The effects of the type of supplement on blood metabolites in dairy cows given grass silage *ad libitum.* **VI World Conference on Animal Production. 27th June to 1st July, 1988, Helsinki.**

Milimo, J. T. (1985) Oxen cultivation in Zambia. University of Zambia, Rural Development Studies Bureau, Research Report 23.

Miller, E. L. (1973) Evaluation of foods as sources of nitrogen and amino acids. **Proc. Nutr. Soc.,** ***32:*** 79-84.

Mitra, R., Christison, G. I. and Johnson, H. D. (1972) Effect of prolonged thermal exposure on growth hormone secretion in cattle. **J. Anim. Sci.,** ***34:*** 776-779.

Moore, J. H. and Christie, W. W. (1981) Lipid metabolism in the mammary gland of lactating ruminants. In: Lipid Metabolism in Ruminant Animals (ed. Christie, W. W.) pp. 227-277. Pergamon Press, Oxford.

Morgan-Rees, A. M., Williams, T. E., Smith, A. J. and Capper, B. S. (1977) Report of an ODM mission to Egypt to undertake a pre-feasibility study of forage production and animal feeds. Tropical Products Institute, London.

Munzinger, P. (1982) Animal Traction in Africa. Deutsche Gesellschaft fur Technische Zusammenarbeit (GTZ), Eschborn, W. Germany.

Nangia, O. P., Rana, R. D., Singh, N. and Ahmed, A. (1978) A note on draught capacity in castrated and entire male buffaloes as reflected by some blood constituents. **Anim. Prod.,** ***27:*** 237-240.

Newsholme, E. A. (1976) Carebohydrate metabolism *in vivo:* regulation of the blood glucose level. **Clinics Endocrinol. Metab.,** ***5:*** 543-578.

Nourrissat, P. (1965) Etudes et Traveaux la Traction Bovin en Senegal. **Agronomie Tropical (Paris),** ***20:*** 823 - 853.

Oldham, J.D. (1978) Utilisation of the end products of protein digestion for lactation. In: Ruminant Digestion and Feed Evaluation. (Eds. Osbourn, D.F., Beaver, D.E. and Thompson, D.J.). pp. 13.1-13.4. A.R.C. London.

Oldham, J.D. (1985) Partition of nutrients in the pregnant and lactating dairy cow. In: Proceedings of the XII International Congress of Nutrition pp. 607-611. (Eds. T.G. Taylor and N.K. Jenkins) London, John Libbey.

Oldham, J.D. and Friggens, N.C. (1989) Sources of variability in lactational performance. **Proc. Nutr. Soc.** ***48***: 33 - 43.

Oldham, J.D. and Smith, T. (1982) Protein energy interrelationships of growing and lactating cattle. In: Miller, E.L., Pike, I.H. and van Es, A.J.H. (Eds). Protein contribution of feedstuffs for ruminants: application to feed formulation. Butterworth Scientific Publishers, London.

Oldham, J.D., Buttery, P.J, Swan, H. and Lewis, D. (1977) Interactions between dietary carbohydrates, nitrogen and digestion in sheep. **J. Agric. Res. Camb.,** ***89***: 467-479.

Oldham, J.D., Fulford, R.J. and Napper, D.J. (1981) Source and level of supplemental N for cows early in lactation. **Proc. Nutr. Soc.,** ***40***: 30A.

Orr, A.W., Islam, A.S.M.N. and Haq, M.M. (1986) Constraints on turnaround time in Bangladesh. Economic Division B.R.R.I., Dhaka, Bangladesh.

Ortigues, I. (1987) Nutrient supply, growth and calorimetric efficiency in heifers offered straw rich diets. Ph.D. Thesis University of Reading.

Palmquist, D.L. (1972) Palmitic acid as a sourc of endogenous acetate and β Hydroxybutyrate in fed and fasted ruminants. **J. Nutr.,** ***102:*** 1401-1406.

Parker, D.S. (1984) Metabolic limits to milk production in the tropics. **Trop. Anim. Prod.,** ***9***: 251-256.

Peaker, M.C. (1980) Influence of diet on the yields and contents of lactose and minerals in milk. **Bulletin of the International Dairy Federation Document,** ***125:*** 159-166.

Pearson, R.A. (1985) Physiological changes associated with work: some lessons from the horse. In: Copland, J.W. (Ed) Draught Animal Power for Production. ACIAR Proceedings Series 10. James Cook University.

Pearson, R.A. (1986) Feeding and management of draught animals: a review. **Indian J. Anim. Prod. Mgmt.,** ***2:*** 48-49.

Pearson, R.A. and Archibald, R.A. (1989) Biochemical and haematological changes associated with short periods of work in draught oxen. **Anim. Prod.**, ***48***: 375-384

Penning, P.D., Orr, R.J. and Treacher, T.T. (1988) Responses of lactating ewes offered fresh herbage indoors and when grazing, to supplements containing differing protein concentrations. **Anim. Prod.**, ***46***: 403-415.

Petheram, R.J., Thahar, A. and Bernsten, R.H. (1985) Socio-economic aspects of draught animal power in south east Asia, with special reference to Java. In: Copland, J.W. (Ed) Draught power for production. Proceedings of an international workshop held at James Cook University, Townsville, Queensland.

Pethick, D.W. (1982) Fatty acid metabolism of ovine skeletal muscle at rest and during exercise. **Proc. Nutr. Soc. Aust.**, *7:* 210.

Pethick, D.W. (1984) Energy metabolism in skeletal muscle. In: Ruminant physiology: concepts and consequences (Eds. S.K. Baker, J.M. Gawthorne, J.B. MacKintosh anbd D.B. Purser). Univesity of Western Australia, Perth. pp. 277-287.

Pethick, D.W. and Lindsay, D.B. (1982a) Metabolism of ketone bodies in pregnant sheep. **Br. J. Nutr.**, ***48***: 549-563.

Pethick, D.W. and and Lindsay, D.B. (1982b) Acetate metabolism in lactating sheep. **Br. J. Nutr.**, ***48:*** 319-328.

Pethick, D.W., Lindsay, D.B., Barker, P.J. and Northrop, A.J. (1981) Acetate supply and utilisation of the tissues of the sheep *in vivo*. **Br. J. Nutr.**, ***46:*** 97-10.

Pethick, D.W. Harman, N. and Chong, J.K. (1987) Non-esterified Long Chain Fatty Acid Metabolism in fed sheep at rest and during exercise. **Aust. J. Biol. Sci.**, ***40:*** 221-234.

Popjak, G., French, T.H. and Folley, S.J. (1951) Utilisation of acetate for milk fat synthesis in the lactating goat. **Biochem J.**, ***48:*** 411-416.

Popjak, G., French, T.H., Hunter, G.D. and Martin, A.J.P. (1951) Mode of formation of milk fatty acids from acetate in the goat. **Biochem J.**, ***48***: 612-618.

Preston, T.R. and Leng, R.A.C. (1987) Matching Ruminant production systems with available resources in the tropics and sub-tropics.

Puri, S.S. (1982) A case for draught. **Asian Livestock**, ***7(10)***: 75.

Rajapurohit, A.R. (1979) Cross-breeding of Indian cattle: An evaluation. In: Economic and Political Weekly, A Sameeksha Trust Publication.

Rajapurohit, A. R. and Muranjan, S. M. (1965) Economics of livestock enterprises: Use of cows for draught purposes. **Indian Journal of Agricultural Economics,** *20:* 121 - 129.

Ranjhan, S. K. (1983) Carabaos in the Philippines: Priorities for research and development. **World Animal Review,** *46:* 26 - 34.

Rep. Zam. (1985) Draught Animal Power. Investment Plan Task Force, Planning Division, MAWD, Lusaka, Zambia.

Ribeiro, J. M. de CR, Brockway, J. M., Webster, A. J. F. (1977) A note on the energy cost of walking in cattle. **Anim. Prod.,** *25:* 107-110.

Rizwan-ul-Muqtadir, Gill, R. A., Ahmad, M. and Ahmad, Z. (1975) Draught Power and its Effect on Milk Yield and Milk Composition in Lactating Buffaloes during the Winter Season. **Pakistan Journal of Agricultural Science,** *12:* 93 - 98.

Robinson, J. J., Fraser, C., Gill, J. C. and McHattie, J. (1974) The effect of dietary crude protein concentration and time of weaning on milk production and body weight change in the ewe. **Anim. Prod.,** *19:* 331-339.

Robinson, J. J., McHattie, J., Calderon Cortes, J. F. and Thompson, J. L. (1979) Further studies on the responses of lactating ewes to dietary protein. **Anim. Prod.,** *29:* 257-269.

Rollinson, D. H. L. and Nell, A. J. (1973) The present and future situation of working cattle and buffaloes in Indonesia. UNDP/FAO project INS/72/009. FAO, Rome.

Rook, J. A. F. (1976) Nutritional influences on milk quantity. In: Principles of cattle production (Eds. H. Swan and W. H. Broster) pp. 221-236. Butterworth, London.

Rook, J. A. F. and Hopwood, J. B. (1970) The effects of intravenous infusions of insulin and sodium succinate on milk secretion in the goat. **J. Dairy Res.,** *37:* 193-198.

Rook, J. A. F. and Thomas, P. C. (1983) Nutritional Physiology of farm animals. Longman, London, Ch. 8.

Rook, J. A. F. and Wood, M. (1959) Potassium and lactose in milk in relation to the physiology of milk secretion. **Nature, London.,** *184:* 647-648.

Rook, J. A. F., Storry, J. E. and Wheelock, J. V. (1965) Plasma glucose and acetate and milk secretion in the ruminant. **J. Dairy. Sci.,** *48:* 745-747.

Sasimowski, E., Slomka, Z. and Halewicz, Anna. (1984) The use of dairy cows for draught purposes in Silesian Poland. Draught Animal News 2, CTVM, University of Edinburgh.

Shalash, M.R. (1983) Productive strategy of buffaloes as economic producers under the Egyptian environment. In Shimizu, H. (Ed) Current development and problems in swamp buffalo production. Proceedings of the pre-conference symposium of the 5th world conference on animal production, Tsukubu, Japan, 1983.

Sharma, K.C. (1982) Some Aspects of Draught Cow Power for Agriculture. In: National seminar on draught animal power systems in India. Indian Institute of Management, Bangalore.

Singh, S.P., Soni, B.K. and Bhattacharyya, N.K. (1968) Haematological changes evoked by exercise in walking bullocks. **Indian Vet. J.,** ***45:*** 212-216.

Singhal, O.P. and Tomar, S.S. (1982) Measurement of Draftability of Draught Animal Power. Indian Institute of Management, Bangalore.

Slangantillake, S. (1983) Draught animal power in Sri Lanka. Asian Livestock 8(10): 76 - 77.

Smith, C.A. (1961) Studies in the Rhodesian Hyparrhenia veld. III. The effect on the growth and grazing behaviour of indigenous cattle of restricting the daily grazing times by night kraaling. **J. Agric. Sci. Camb.,** ***56:*** 243-248.

Smith, A.J. (1980) The role of draught animals in agricultural systems in developing countries. In: Vegetables for feeding people and livestock. Institute of Biology, London.

Snoswell, A.M., Costa, N.D., McLean, J.G., Baird, G.D., Lomax, M.A. and Symonds, H.W. (1978) Interrelationships between acetylation and disposal of acetyl groups in the livers of cows. **J. Dairy Res.,** ***45:*** 331-338.

Starkey, P.R. (1981) Farming with work oxen in Sierra Leone. Report of the Sierra Leone Work Oxen Project. Ministry of Agriculture, Tower Hill, Freetown.

Storry, J.E.C. (1980) Influence of Nutritional factors on the yield and content of milk fat: Non protected fat in the diet. **Bulletin of the Internaitonal Dairy Federation Document 25, 88-95.**

Suntraporn, R.N.P. (1975) The Improvement of Buffalo Production through Breeding and Management under Thailand Conditions. In: The Asiatic Buffalo. The Food and Fertiliser Centre, Taiwan.

Sutton, J.D. (1980) Influence of nutritional factors on the yield and content of milk fat: dietary components other than fat. **Bulletin of the International Diary Federation, Document** ***125,*** 126-134.

Sutton, J.D. (1985) Digestion and Absorption of energy substrates in the lactating cow. **J. Dairy Sci.,** ***68:*** 3376-3393.

Sutton, J.D. and Oldham, J.D. (unpublished) quoted by Sutton (1985). Ibid.

Sutton, J.D., Oldham, J.D. and Hart, I.C. (1980) Products of digestion, hormones and energy utilisation in milking cows given concentrates containing varying proportions of barley and maize. In Energy Metabolism. Ed. L.E. Mount, Butterworths, London.

Swaid, A.H., Sing, R.A., Sastry, N.S.R. and Georgie, G.C. (1986) Blood composition profile of zebu-taurus crossbred cattle and its managemental implications. **Ind. J. Anim. Sci.,** ***56:*** 1077-1085.

Tagari, H. and Bergman, E.N.C. (1978) Intestinal disappearance and portal blood appearance of amino acids in sheep. **J. Nutr.,** ***108:*** 790-803.

Tamminga, S., van der Koelen, C.J. and van Vuuren, A.M. (1979) Effect of the level of feed intak e on nitrogen entering the small intestine of dairy cows. **Livestsock Production Science,** ***6:*** 225-262.

Thomas, P.C. (1980) Influence of nutrition on the yield and content of protein in milk: dietary protein and energy supply. **Bulletin of the Internaitornal Dairy Federation Document, 125,** 142-151.

Thompson, G.E. (1973) Climatic physiology of cattle. **J. Dairy Sci.** ***40:*** 441 - 473.

Thompson, R.D., Johnston, J.E., Breidenstein, C.P., Guidry, AJ., Banerjee, M.R. and Burnett, W.T. (1963) Effect of hot climates on adrenal cortical, thyroidal and other metabolic responses of dairy heifers. **J. Dairy Sci.,** ***46:*** 227-231.

Tornede, H. (1939) The problem of work performance of dairy cows with special reference to hill cattle. Zuchtungskunde, 14: 308 - 333. **Animal Breeding Abstracts** 8: 230; 1940.

Tove, S.B. (1965) Fat metabolism in ruminants. In: Physiology and Digestion in Ruminants. Dougherty, R.W. (Ed), Butterworths, Washington.

Trenkle, A. (1980) Amino acid metabolism in ruminants. In: Digestive Physiology and Metabolism in Ruminants. (Eds. Ruckebusch, Y. and Thivend, P.) pp. 505 - 523. MTP Press Ltd., Lancaster.

Upadhyay, R.C. and Madan, M.L. (1985) Studies on blood acid-base status and muscle metabolism in working bullocks. **Anim. Prod.,** ***40:*** 11-16.

Vercoe, J.E. (1969) The effect of increased rectal temperature on nitrogen metabolism in Brahman cross and Shorthorn x Hereford steers fed on lucern chaff. **Aust. J. Agric. Res.,** ***20:*** 607-612.

Vernon, R.G. (1981) Lipid metabolism in the adipose tissue of ruminant animals. In: W.W. Christie (ed) Lipid metabolism in rumimant animals. pp. 280-362. London, Pergamon Press.

Wayman, O., Johnson, H.D., Merilan, C.P. and Berry, I.L. (1962) The effect of *ad libitum* or force feeding of two rations on lactating dairy cows subject to temperature stress. **J. Dairy Sci., *45***: 1472-1478.

Weldy, J.R., McDowell, R.E., van Soest, P.J. and Bond, J. (1964) Influence of heat stress on rumen acid levels and some blood constituents in cattle. **J. Anim. Sci., *23***: 147-153.

Weston, R.H. (1985) Some considerations of voluntary feed consumption and digestion in relation to work. In: Copland, J.W. (Ed) Draught Animal Power for Production. ACIAR Proceedings Series 10, James Cook University, Queensland.

Wiltrout, D.W. and Satter, L.D. (1972) Contribution to propionate to glucose synthesis in the lactating and non-lactating cow. **J. Dairy Sci., *55:*** 307-317.

Winngroho, M. (1988) The effect of work durations on voluntary feed intake and digestibility, liveweights and physiology of buffaloes fed a grass:rice straw diet. Paper presented in the Congress of the Sixth Federation of Asian Veterinary Associations (FAVA), October 16-19, 1988, Depasar, Bali.

Young, J.W. (1977) Gluconeogenesis in cattle: significance and methodology. **J. Dairy Sci., *60:*** 1-15.

Zimbabwe (1985) Annual Report of the Farming Systems Research Unit 1983-1984. Department of Research and Specialist Services, Zimbabwe.

Zirvin, J.A. and Snarr, J.F. (1973) An automated colorimetric method for the measurement of 3-hydroxybutyrate concentration. **Anal. Bioch. *52***: 456-461

APPENDICES

APPENDIX 1A: CALVING DATES FOR COWS IN EXPERIMENTS I AND II AND DAYS POST-PARTUM ON DAY ONE OF THE EXPERIMENT

Experiment I

Cow	Calving Date	Day Post-Partum
8228	03.10.86.	158
8125	10.09.86.	181
8230	07.10.86.	154
8143	02.09.86.	189
8233	02.09.86.	189
8122	11.09.86.	180
8239	04.09.86.	187
8221	10.09.86.	181
8131	06.09.86.	185
8146	11.09.86.	180
8227	17.09.86.	174
8234	08.10.86.	151

Experiment II

8227	08.09.87.	181
8234	16.11.87.	113
8233	18.11.87.	111
8319	08.10.87.	151
8313	23.09.87.	164
8228	21.10.87.	158
8230	05.11.87.	124
8314	16.10.87.	143
8239	08.10.87.	151
8321	07.11.87.	122
8311	26.11.87.	103
836	28.08.87.	192

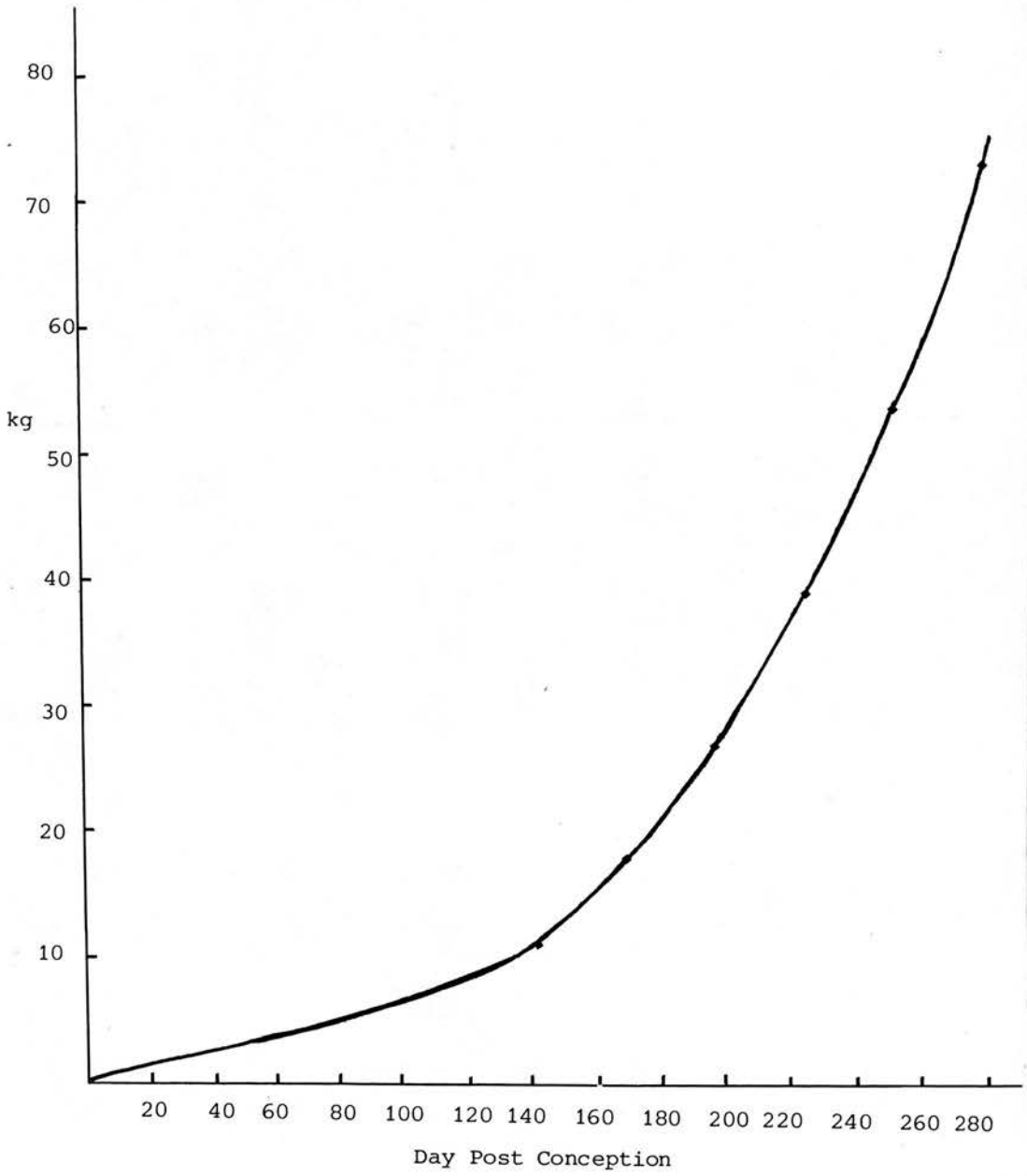
APPENDIX 1B: ESTIMATED GROWTH OF CONCEPTA (ARC, 1980)

ARC (1980) gave the following weights of concepta at progressing stages of pregnancy:

Day from Conception	Weight (kg)
141	11.0
169	17.8
197	26.7
225	38.7
253	53.9
281	72.8

These weights were used to plot the graph in Appendix 1C and this was used to estimate the weight of concepta in each experimental period.

APPENDIX 1C: ESTIMATED WEIGHT OF CONCEPTA (ARC, 1980)



APPENDIX 2A: QUANTITIES OF FEED OFFERED TO EACH COW IN EACH EXPERIMENT

EXPERIMENT I

	RATION OFFERED (kg/d)		
GROUP	Wet	Dry	ME (MJ/kgDM)
WC			
8228	8.6	7.2	74.81
8125	11.1	9.3	96.63
8230	11.3	9.4	97.67
8143	10.4	8.7	90.39
8233	11.2	9.3	96.63
8122	11.3.	9.4	97.67
MEAN	10.65	8.9	92.47
CW			
8239	9.2	7.7	80.00
8221	11.8	9.8	101.82
8131	11.4	9.5	98.71
8146	12.2	10.2	105.98
8227	12.9	10.8	112.21
8234	11.4	9.5	98.71
MEAN	11.48	9.6	99.74

EXPERIMENT II

AA6			
8227	13.2	11.6	120.52
8234	11.3	9.9	102.86
8233	12.7	11.2	116.37
8319	12.1	10.7	111.17
8313	12.0	10.6	110.13
8228	11.1	9.7	100.78
MEAN	12.1	10.6	110.13
HS1			
8230	11.2	9.8	110.64
8314	12.9	11.4	128.71
8239	9.1	8.0	90.32
8321	10.5	9.2	103.89
8311	11.1	9.8	110.64
836	10.5	9.2	103.89
MEAN	10.9	9.6	108.38

1. DM = 83.4% (Experiment I); 88% (Experiment II)
   ME/KgDM = 10.39 (AA6); 11.29 (HS1)

EXPERIMENT III

In Experiment III each animal received 4kg per day of one of three supplements.

The composition of each diet supplement is shown in Table 4.5.

All cows received *ad libitum* barley straw every day.

APPENDIX 2B: INITIAL WEIGHTS AND MILK YIELDS OF COWS IN EACH TREATMENT GROUP IN EACH EXPERIMENT

EXPERIMENT I

GROUP	WEIGHT (kg)	YIELD (kg)
WC		
8228	410	3.3
8125	455	7.1
8230	408	8.0
8143	433	6.1
8233	418	7.6
8122	400	8.0
MEAN	421	6.7
CW		
8239	438	4.0
8221	453	7.5
8131	395	7.9
8146	433	8.5
8227	450	9.2
8234	418	7.5
MEAN	431	7.4

EXPERIMENT II

	WEIGHT (kg)	YIELD (kg)
I (AA6)		
8227	570	10.8
8234	495	9.7
8233	500	10.8
8319	525	9.9
8313	505	9.9
8228	500	6.3
MEAN	516	9.6
II (HS1)		
8230	485	11.1
8314	610	10.8
8239	495	5.0
8321	500	9.2
8311	500	10.7
836	470	9.7
MEAN	510	9.4

EXPERIMENT III

	WEIGHT (kg)	YIELD (kg)
I (HS2)		
7714	443	6.9
7911	472	4.9
799	555	5.1
781	534	5.3
MEAN	501	5.6
II (DF)		
802	565	5.3
8028	548	4.8
7718	436	7.0
7926	476	5.4
MEAN	506	5.6
III (HP)		
798	539	4.9
7725	607	7.1
8313	449	4.7
NoNo.	419	5.9
MEAN	504	5.7

APPENDIX 3A: EXAMPLE OF ANALYSIS OF VARIANCE (EXPERIMENT I)
MILK YIELD

SOURCE OF VARIATION	DF	SS	MS	VR
COW STRATUM				
treat. period	1	1.0375	1.0375	0.275
RESIDUAL	10	37.6801	3.7680	
TOTAL	11	38.7176	3.5198	
cow. *UNITS* STRATUM				
treat	1	2.4003	2.4003	10.150
period	1	11.9145	11.9145	50.380
RESIDUAL	10	2.3649	0.2365	
TOTAL	12	16.6797	1.3900	
GRAND TOTAL	23	55.3973		
GRAND MEAN	5.575			
TOTAL NUMBER OF OBSERVATIONS	24			

Control Mean		=	5.89 (kg)
Walking Mean		=	5.26
Difference		=	0.63
Standard Error of Difference	2xEMS / n	=	0.20
't'	Difference / SED	=	3.15

APPENDIX 3B: EXAMPLE OF REGRESSION ANALYSIS OF VARIANCE (EXPERIMENT II) MILK YIELD

*** SUMMARY ANALYSIS OF VARIANCE ***

Y-VARIATE: MILKY

TERMS	RESIDUAL DF	RESIDUAL SS	CHANGE DF	CHANGE SS	MEAN CHANGE	VARIANCE RATIO
INITIAL MODEL						
CONSTANT	431	3471.352	*	*		
MODIFICATIONS TO MODEL						
+COVAR(1)	430	2268.487	1	1202.865	1202.865	325.17
+DIET	429	2150.142	1	118.345	118.345	31.99
+DAY	428	1624.743	1	525.399	525.399	142.03
+TREATMEN	427	1583.967	1	40.777	40.777	11.02
+DIET.TREATMEN	426	1583.709	1	0.257	0.257	0.07
+DAY.TREATMEN	425	1572.159	1	11.550	11.550	3.12
* DENOMINATOR OF RATIO IS RES. SS /RES. DF FROM LINE ABOVE.=					3.699	

497.....

***** PREDICTIONS FROM REGRESSION MODEL *****

TABLE CONTAINS PREDICTIONS FOLLOWED BY STANDARD ERRORS

Y-VARIATE: MILKY

DIET		
AA6	6.920	0.131
HS1	7.971	0.131

497.....

***** PREDICTIONS FROM REGRESSION MODEL *****

TABLE CONTAINS PREDICTIONS FOLLOWED BY STANDARD ERRORS

Y-VARIATE: MILKY

TREATMEN		
CONTROL	7.663	0.113
WALKING	7.011	0.160

497.....

***** PREDICTIONS FROM REGRESSION MODEL *****

TABLE CONTAINS PREDICTIONS FOLLOWED BY STANDARD ERRORS

Y-VARIATE: MILKY

TREATMEN	CONTROL		WALKING	
DIET				
AA6	7.154	0.161	6.451	0.227
HS1	8.171	0.161	7.571	0.227

APPENDIX 3C: EXAMPLE OF REGRESSION ANALYSIS OF VARIANCE (EXPERIMENT III) MILK YIELD

*** SUMMARY ANALYSIS OF VARIANCE ***

Y-VARIATE: MILKY

TERMS	RESIDUAL DF	RESIDUAL SS	CHANGE DF	CHANGE SS	MEAN CHANGE	VARIANCE RATIO
INITIAL MODEL						
CONSTANT	431	1.544E 3	*	*		
MODIFICATIONS TO MODEL						
+Covar(1)	430	9.908E 2	1	5.536E 2	5.536E 2	798.13
+Diet	428	7.543E 2	2	2.365E 2	1.183E 2	170.48
+Day	427	3.097E 2	1	4.446E 2	4.446E 2	640.95
+Treatmen	426	2.955E 2	1	1.418E 1	1.418E 1	20.45
* DENOMINATOR OF RATIO IS RES. SS /RES. DF FROM LINE ABOVE, =					6.936E -1	
+Diet.Treatmen	424	2.955E 2	2	1.190E -2	5.951E -3	0.01
+Day.Treatmen	423	2.942E 2	1	1.298E 0	1.298E 0	1.87

500.....

***** PREDICTIONS FROM REGRESSION MODEL *****

TABLE CONTAINS PREDICTIONS FOLLOWED BY STANDARD ERRORS

Y-VARIATE: MILKY

Diet		
HS	4.5388	0.0695
DF	2.7453	0.0697
HP	3.9013	0.0696

500.....

***** PREDICTIONS FROM REGRESSION MODEL *****

TABLE CONTAINS PREDICTIONS FOLLOWED BY STANDARD ERRORS

Y-VARIATE: MILKY

Treatmen		
Control	3.8566	0.0491
Walking	3.4722	0.0695

500.....

***** PREDICTIONS FROM REGRESSION MODEL *****

TABLE CONTAINS PREDICTIONS FOLLOWED BY STANDARD ERRORS

Y-VARIATE: MILKY

Treatmen	Control		Walking	
Diet				
HS	4.6677	0.0851	4.2812	0.1204
DF	2.8776	0.0853	2.4807	0.1205
HP	4.0246	0.0852	3.6548	0.1204

APPENDIX 3D: EXAMPLE OF ANALYSIS OF VARIANCE
(EXPERIMENTS II AND III) β-OH BUTYRATE

VARIATE: BHB

SOURCE OF VARIATION	DF	SS	SS%	MS	VR
ANIMAL STRATUM					
DIET	1	0.35065	2.14	0.35065	1.229
RESIDUAL	10	2.85417	17.38	0.28542	
TOTAL	11	3.20482	19.52	0.29135	
ANIMAL.WEEK STRATUM					
TREATMEN	1	5.58747	34.03	5.58747	76.950
DIET.TREATMEN	1	0.79986	4.87	0.79986	11.016
RESIDUAL	94	6.82546	41.57	0.07261	
TOTAL	96	13.21278	80.48	0.13763	
GRAND TOTAL	107	16.41759	100.00		

GRAND MEAN 0.968
TOTAL NUMBER OF OBSERVATIONS 108

VARIATE: BHB (488

SOURCE OF VARIATION	DF	SS	SS%	MS	VR
ANIMAL STRATUM					
DIET	2	0.88048	4.38	0.44024	2.724
RESIDUAL	9	1.45452	7.23	0.16161	
TOTAL	11	2.33500	11.61	0.21227	
ANIMAL.WEEK STRATUM					
TREATMEN	1	11.40534	56.70	11.40534	185.875
DIET.TREATMEN	2	0.66893	3.33	0.33446	5.451
RESIDUAL	93	5.70650	28.37	0.06136	
TOTAL	96	17.78075	88.39	0.18522	
GRAND TOTAL	107	20.11574	100.00		

GRAND MEAN 0.714
TOTAL NUMBER OF OBSERVATIONS 108

APPENDIX 3E: ANALYSES OF VARIANCE OF PERIOD MEANS FOR MILK YIELDS, MILK CONSTITUENT YIELDS AND MILK CONSTITUENT CONTENTS FOR EXPERIMENTS II AND III

SEE OVER

Cows - Control v Walking 1987

(All adjusted by using weeks 1-3 data as covariate)

Milk Yield

Grand mean 7.34

Diet	1	2	sed.	
	7.11	7.57	1.264	no sig. diff.

Treatment	Control	Walking	sed.	
	7.66	7.01	0.212	(P<0.05)

Percentage Fat

Grand mean 3.795

Diet	1	2	sed.	
	3.962	3.629	0.3398	no sig. diff.

Treatment	Control	Walking	sed.	
	3.618	3.972	0.0956	(P<0.01)

Percentage Protein

Grand mean 3.758

Diet	1	2	sed.	
	3.741	3.775	0.1615	no sig. diff.

Treatment	Control	Walking	sed.
	3.779	3.738	0.0650

Percentage Lactose

Grand mean 4.656

Diet	1	2	sed.	
	4.662	4.650	0.1328	no sig. diff.

Treatment	Control	Walking	sed.
	4.676	4.636	0.0418

Milk Fat Yield

Grand mean 271.3

Diet	1	2	sed.	
	276.0	266.6	55.35	no sig. diff.

Treatment	Control	Walking	sed.	
	270.2	272.4	10.43	no sig. diff.

Milk Protein Yield

Grand mean 266.0

Diet	1	2	sed.	
	259.0	273.1	41.86	no sig. diff.

Treatment	Control	Walking	sed.	
	276.4	255.7	7.19	($P<0.05$)

Lactose Yield

Grand mean 347.2

Diet	1	2	sed.	
	336.5	357.9	60.46	no sig. diff.

Treatment	Control	Walking	sed.	
	364.1	330.3	10.76	($P<0.05$)

Cows - Control v Walking 1988

(All adjusted by using weeks 1-3 data as covariate)

Milk Yield

Grand mean 3.664

Diet	HS	DF	HP	sed.	
	4.191	2.802	4.000	0.5990	no sig. diff.

Treatment	Control	Walking	sed.	
	3.857	3.472	0.068	(P<0.001)

Percentage Fat

Grand mean 4.022

Diet	HS	DF	HP	sed.	
	3.970	3.380	4.267	0.4086	no sig. diff.

Treatment	Control	Walking	sed.	
	3.674	4.370	0.0931	(P<0.001)

Percentage Protein

Grand mean 3.545

Diet	HS	DF	HP	sed.	
	3.268	3.363	4.005	0.3452	no sig. diff.

Treatment	Control	Walking	sed.
	3.562	3.528	0.043

Percentage Lactose

Grand mean 4.353

Diet	HS	DF	HP	sed.	
	4.532	4.023	4.505	0.2079	no sig. diff.

Treatment	Control	Walking	sed.	
	4.400	4.307	0.0561	(P<0.05)

Milk Fat Yield

Grand mean	146.9				
Diet	HS	DF	HP	sed.	
	152.6	116.0	172.1	26.66	no sig. diff.
Treatment	Control		Walking	sed.	
	142.9		150.8	2.76	(P<0.05)

Milk Protein Yield

Grand mean	122.9				
Diet	HS	DF	HP	sed.	
	134.9	89.1	144.8	17.24	(P<0.05)
Treatment	Control		Walking	sed.	
	127.7		118.2	2.68	(P<0.01)

Lactose Yield

Grand mean	166.6				
Diet	HS	DF	HP	sed.	
	192.7	122.4	184.7	28.60	no sig. diff.
Treatment	Control		Walking	sed.	
	178.8		154.4	3.16	(P<0.001)

APPENDIX 4A: MEAN ('NORMAL') VALUES FOR BLOOD PARAMETER CONCENTRATIONS

	Mean	Normal Range
Plasma Glucose (mmol/l)	3.27	3.05 - 3.49[1]
		2.10 - 3.00[2]
Plasma Urea (mmol/l)	2.40	1.57 - 3.23[1]
		1.60 - 3.40[2]
Serum β-OH Butyrate (mmol/l)		
Dry	-	0.24 - 0.53[1]
Mid Lactation	-	0.24 - 0.63[1]
Early Lactation	-	0.24 - 0.96[1]
Serum Free Fatty Acids (m equiv/l)		0.61 - 0.78[3]
Serum Albumin (g%)	3.4	2.90 - 3.90[1]
Serum Globulin (g%)	4.3	3.10 - 5.50[1]
Inorganic Phosphorus (mg/100ml)	6.0	4.30 - 7.70[1]
		3.60 - 7.20[2]
Magnesium (mg/100ml)	2.5	2.00 - 3.00[1]
		2.20 - 3.00[2]

Sources:

1. THE DAIRY HERD HEALTH AND PRODUCTIVITY SERVICE, EASTER BUSH, EDINBURGH.

2. Collins and Kelly (1977)

3. Swaid, Sing, Sastry and Georgie (1986)

APPENDIX 4B: MEAN VALUES FOR BLOOD METABOLITE CONCENTRATIONS IN EXPERIMENT II

METABOLITE	DIET	WEEK								
		1	2	3	4	5	6	7	8	9
β-OH butyrate	AA6	1.12	0.69	0.79	1.46	1.63	1.32	0.76	0.88	0.62
(serum)	HS1	0.87	0.63	1.05	1.38	0.82	1.14	0.75	0.74	0.79
(m mols/l)	Mean	1.00	0.66	0.92	1.46	1.23	1.23	0.76	0.81	0.71
Glucose	AA6	3.94	3.90	4.10	3.12	3.58	4.02	3.80	3.58	3.98
(plasma)	HS1	4.39	4.04	3.96	3.01	3.63	4.05	3.76	3.69	4.02
(m mols/l)	Mean	4.17	3.97	4.03	3.07	3.61	4.03	3.78	3.63	4.00
Urea	AA6	3.10	2.52	2.60	2.78	3.53	3.30	2.62	2.85	2.97
(plasma)	HS1	3.30	2.42	2.82	3.23	3.55	3.53	2.80	3.03	3.13
(m mols/l)	Mean	3.20	2.48	2.71	3.01	3.54	3.42	2.71	2.94	3.05
Free Fatty Acids	AA6	0.15	0.15	0.21	2.25	1.01	-	-	-	-
(serum)	HS1	0.21	0.26	0.06	1.38	0.99	-	-	-	-
(m Eq/l)	Mean	0.18	0.21	0.14	1.82	1.00	-	-	-	-
Albumin	AA6	2.9	2.9	2.9	3.4	3.3	3.4	3.2	3.3	3.4
(serum)	HS1	2.9	2.7	2.9	3.0	3.0	3.2	3.3	3.1	3.2
(g%)	Mean	2.9	2.8	2.9	3.2	3.2	3.3	3.3	3.2	3.3
Globulin	AA6	4.5	4.2	4.4	3.8	4.4	4.2	4.2	3.9	4.2
(serum)	HS1	4.7	4.5	4.4	4.2	4.7	4.4	4.3	4.4	4.6
(g%)	Mean	4.6	4.4	4.4	4.0	4.6	4.3	4.3	4.2	4.4
Magnesium	AA6	1.7	2.1	2.2	2.2	1.9	2.1	2.3	2.2	2.4
(serum)	HS1	1.9	2.2	2.5	2.2	2.1	2.5	2.6	2.5	2.6
(mg/100ml)	Mean	1.8	2.2	2.4	2.2	2.0	2.3	2.5	2.4	2.5
Phosphorus	AA6	9.5	7.4	7.7	4.4	6.7	6.6	6.6	6.7	7.2
(plasma)	HS1	9.0	6.2	6.6	5.7	6.5	7.2	7.1	6.8	7.2
(mg/100ml)	Mean	9.3	6.8	7.2	5.1	6.6	6.9	6.9	6.8	7.2

APPENDIX 4C: MEAN VALUES FOR BLOOD METABOLITE CONCENTRATIONS IN EXPERIMENT III

METABOLITE	DIET	WEEK								
		1	2	3	4	5	6	7	8	9
β-OH butyrate	HS2	0.45	0.25	0.36	0.77	1.04	0.91	0.50	0.48	0.56
(serum)	DF	0.41	0.46	0.59	0.99	1.59	1.10	0.68	0.51	0.55
(m mols/l)	HP	0.41	0.44	0.54	1.21	1.64	1.34	0.57	0.63	0.53
Glucose	HS2	3.22	3.42	3.56	3.53	3.00	3.14	3.56	3.49	3.52
(plasma)	DF	3.28	3.33	3.67	3.28	2.82	3.42	3.68	3.54	3.56
(m mols/l)	HP	3.27	3.43	3.68	3.49	2.98	3.23	3.65	3.69	3.56
Urea	HS2	3.27	2.65	2.85	2.62	2.60	3.33	3.08	3.22	3.25
(plasma)	DF	3.17	3.13	2.93	2.75	2.47	3.55	3.25	3.47	3.25
(m mols/l)	HP	2.98	3.78	3.88	4.60	4.88	5.75	5.00	4.92	4.92
Free Fatty Acids	HS2	0.88	0.57	0.59	0.72	1.61	1.06	0.49	0.42	0.47
(serum)	DF	0.88	0.95	0.60	0.62	1.19	0.91	0.52	0.36	0.44
(m Eq/l)	HP	0.68	0.78	0.76	0.79	1.03	0.81	0.37	0.23	0.41
Albumin	HS2	3.3	3.3	3.3	3.2	3.2	3.1	3.4	3.4	3.4
(serum)	DF	3.5	3.5	3.4	3.4	3.2	3.2	3.4	3.3	3.5
(g%)	HP	3.6	3.5	3.6	3.5	3.4	3.3	3.6	3.3	3.5
Globulin	HS2	3.4	4.2	4.6	3.8	3.8	4.0	4.0	4.1	3.8
(serum)	DF	3.4	4.0	4.1	3.6	3.7	3.9	4.1	4.1	3.9
(g%)	HP	3.8	4.0	4.1	3.8	3.7	3.9	4.0	3.9	4.2
Magnesium	HS2	1.8	2.4	2.3	2.0	1.9	2.0	2.2	2.2	2.2
(serum)	DF	2.1	2.4	2.2	2.0	1.9	2.0	2.2	2.2	2.3
(mg/100ml)	HP	2.1	2.2	2.0	1.7	1.7	1.7	2.1	1.9	2.0
Phosphorus	HS2	7.4	7.3	6.8	3.7	3.9	3.2	5.3	6.6	5.7
(plasma)	DF	5.3	5.9	5.3	4.0	3.6	3.3	6.3	6.4	5.1
(mg/100ml)	HP	7.1	6.7	6.6	5.4	5.5	5.7	6.9	6.2	6.3

APPENDIX 4D: MEAN VALUES FOR BLOOD METABOLITE CONCENTRATIONS FOR FRIDAY, SATURDAY AND SUNDAY IN WEEK FIVE OF EXPERIMENT III

METABOLITE	DIET	DAY OF WEEK 5		
		Friday	Saturday	Sunday
β-OH butyrate	HS2	0.76	0.46	0.35
(serum)	DF	1.30	0.62	0.75
(m mols/l)	HP	1.57	0.68	0.49
Glucose	HS2	3.40	3.67	3.56
(plasma)	DF	3.14	3.64	3.90
(m mols/l)	HP	3.16	3.75	3.73
Urea	HS2	2.97	2.80	2.75
(plasma)	DF	2.63	3.08	2.80
(m mols/l)	HP	5.02	4.80	4.50
Free Fatty Acids	HS2	1.54	0.77	0.47
(serum)	DF	1.31	0.85	0.57
(meqs/l)	HP	1.35	0.73	0.62
Magnesium	HS2	1.90	2.20	2.20
(serum)	DF	2.00	2.20	2.10
(mg/100ml)	HP	1.70	1.50	1.80
Phosphorus	HS2	2.70	5.30	5.20
(plasma)	DF	2.40	5.50	5.50
(mg/100ml)	HP	5.50	7.00	6.50

APPENDIX 5A: WEIGHTS AND MEAN WEIGHTS (kg) OF COWS IN EACH PERIOD[1] OF EXPERIMENT I

		Cow Number							Cow Number						
PERIOD		28	25	30	43	33	22	MEAN SE	39	21	31	46	27	34	MEAN SE
	Weighing			WALKING							NON-WALKING				
	1	410	455	410	435	425	410	424 6.8	440	460	405	430	460	425	437 8.0
	2	400	445	420	425	425	410	421 5.7	435	440	400	425	460	425	431 7.4
I	3	410	450	420	435	425	425	428 5.1	445	460	400	430	465	425	438 9.0
	4	405	455	420	445	430	430	431 6.6	450	465	400	435	465	430	441 9.2
	5	405	455	425	445	430	410	428 7.2	455	475	410	440	475	430	448 9.6
	MEAN	406	452	419	437	427	417		445	460	403	432	465	427	
				NON-WALKING							WALKING				
	6	410	460	430	450	430	420	433 6.9	460	475	410	440	470	435	448 9.2
	7	420	470	425	455	455	425	442 7.8	460	475	420	445	470	440	452 7.7
II	8	425	470	440	460	455	430	447 6.6	455	475	420	440	470	435	449 7.9
	9	430	475	445	460	455	435	450 6.2	465	485	430	455	480	445	460 7.8
	10	435	470	450	465	465	440	454 5.5	465	475	425	450	485	445	458 8.1
	11	440	480	460	480	475	460	466 5.8	460	480	430	450	485	450	459 7.7
	MEAN	427	471	442	462	456	435		461	478	423	447	477	442	

1. Cows were weighed twice a week except in week 3 when they were weighed only once

APPENDIX 5B: WEIGHTS AND MEAN WEIGHTS (kg) OF COWS IN PERIODS I, II AND III IN EXPERIMENT II

COW	PERIOD I			PERIOD II					PERIOD III				
	4/6	16/6	mean	23/6	28/6	2/7	9/7	mean	13/7	22/7	28/7	31/7	mean
8227	570	610	590	611	604	580	568	591	574	600	602	624	600
8234	495	505	500	507	502	505	504	505	504	516	536	538	524
8233	500	510	505	516	502	505	506	507	514	526	538	546	531
8319	525	535	530	542	550	548	540	545	546	574	582	584	572
8313	505	505	505	510	520	498	496	506	502	525	526	538	523
8228	500	520	510	528	528	518	522	524	522	555	564	576	550
mean	516	531	523	536	534	526	523	530	527	549	558	568	550
SE	10.6	15.1	-	14.6	14.4	11.9	10.1	-	10.4	12.3	11.1	12.6	-
8230	485	495	490	498	500	500	508	502	508	524	524	536	523
8314	610	630	620	621	622	618	620	620	630	630	642	652	639
8239	495	525	510	528	532	520	520	525	532	552	568	578	558
8321	500	515	507	528	524	510	515	519	514	530	532	556	533
8311	500	520	510	510	518	506	505	510	516	532	544	546	535
836	470	485	480	490	498	495	480	482	490	504	506	520	505
mean	510	528	519	529	532	525	525	528	532	545	553	565	549
SE	18.7	19.4	-	17.7	17.1	17.3	18.2	-	18.7	16.5	18.0	17.5	-
PERIOD MEAN			521					529					550

COWS 8227 to 8228 OFFERED DIET AA6

COWS 8230 to 836 OFFERED DIET HS1

APPENDIX 5C: Weights and mean weights of cows in each period on fed each diet in Experiment III

COW																		
7714	442	457	430	445	455	442	447	437	437	451	440	441	444	434	442	440	435	448
781	513	529	527	505	526	522	535	537	542	544	545	546	546	546	563	569	568	563
7911	457	456	462	461	475	468	481	460	464	455	470	461	460	474	489	483	484	489
799	550	544	548	537	538	533	545	525	532	514	520	512	519	518	527	532	527	534
mean	491	497	494	487	499	491	502	490	493	491	493	490	492	493	505	506	504	509
7718	427	424	429	413	418	437	427	422	422	426	415	413	421	425	424	427	432	433
802	555	547	554	542	544	551	558	557	556	556	545	553	562	564	562	561	564	572
7926	466	463	462	455	450	454	465	460	474	463	460	456	462	466	465	477	486	492
8028	527	524	527	518	520	518	526	510	513	506	510	505	509	517	528	536	526	534
mean	494	489	493	482	483	490	494	487	491	488	483	481	489	493	495	500	502	508
NoNo	427	432	442	441	451	434	445	435	448	436	450	442	448	462	464	474	481	482
8313	449	458	458	460	473	473	490	487	492	477	480	478	474	493	507	515	515	522
7725	588	603	609	597	610	606	612	602	617	617	610	606	618	622	628	636	643	641
798	538	538	538	528	543	536	550	538	552	542	545	543	539	534	562	550	564	567
mean	501	508	512	507	519	512	524	516	527	518	521	517	520	528	540	544	551	553

APPENDIX 6A: CONDITION SCORES OF EACH COW IN EACH PERIOD IN EXPERIMENT I

Cow No.	Period I	Period II
	Walking	Control
28	1.75	2.00
25	1.50	1.75
30	1.75	1.75
43	2.00	2.00
33	1.75	1.75
22	1.75	1.75
	Control	Walking
39	2.00	2.00
21	2.00	2.00
31	1.75	1.75
46	1.75	1.75
27	1.75	1.75
34	1.75	1.75

APPENDIX 6B: CONDITION SCORES OF EACH COW IN PERIOD III IN EXPERIMENT II

COW	DIET	CONDITION SCORE
8227	AA6	2.25
8234	AA6	2.00
8233	AA6	2.25
8319	AA6	2.25
8313	AA6	2.00
8228	AA6	2.25
8230	HS1	2.00
8314	HS1	2.50
8239	HS1	2.50
8321	HS1	2.00
8311	HS1	1.75
836	HS1	2.00

APPENDIX 6C: CONDITION SCORES OF EACH COW IN EACH PERIOD IN EXPERIMENT III

Diet	Cow No.	Period I 1.6.88.	Period II 6.7.88.	Period III 6.8.88
HS2	7714	2.00	2.00	1.75
	781	2.00	2.00	1.75
	7911	1.75	2.25	2.00
	799	2.25	2.50	2.25
DF	7718	1.75	1.75	1.50
	802	2.50	2.25	2.00
	7926	1.75	2.00	2.00
	8028	2.50	2.00	2.00
HP	NoNo.	1.75	1.75	1.75
	8313	1.75	1.75	1.75
	7725	2.50	2.25	2.00
	798	2.25	2.50	2.00

APPENDIX 7: MEAN DAILY STRAW INTAKE FOR FOR EACH COW FOR EACH WEEK IN EXPERIMENT III

		WEEK								
	COW	1	2	3	4	5	6	7	8	9
HS2	7714	4.14	4.28	5.23	4.86	5.10	5.21	5.44	5.11	5.59
	781	3.56	4.00	4.86	4.96	5.25	5.49	6.27	5.79	5.90
	7911	3.84	3.64	4.46	3.93	4.15	4.52	5.35	5.17	5.27
	799	3.96	3.65	4.48	3.81	3.96	3.99	4.64	4.33	4.68
	mean	3.88	3.89	4.76	4.39	4.62	4.80	5.43	5.10	5.36
DF	7718	3.36	3.36	4.18	3.53	3.87	4.23	4.71	4.47	4.60
	802	4.08	3.73	4.33	4.58	4.52	5.07	5.26	5.04	4.95
	7926	3.93	3.53	4.38	4.25	4.25	4.57	4.97	4.77	4.89
	8028	4.67	4.93	5.10	4.62	4.73	4.94	5.23	5.08	5.52
	mean	4.01	3.89	4.50	4.25	4.34	4.70	5.04	4.84	4.99
HP	NoNo	4.60	4.53	5.05	4.80	5.02	5.41	5.60	5.65	5.74
	8313	4.88	5.07	5.50	5.38	5.12	5.48	6.08	5.71	6.29
	7725	4.38	3.96	5.32	4.92	5.38	5.35	5.91	5.77	6.12
	798	3.36	3.29	4.37	4.40	4.68	4.68	5.33	4.52	5.08
	mean	4.31	4.21	5.06	4.88	5.05	5.23	5.73	5.41	5.81

APPENDIX 8: BASIC DATA AND ASSUMPTIONS FOR ENERGY BALANCES

Unless otherwise stated, the following calculations are based on equations taken from MAFF (1975).

EXPERIMENT I

A. ME Intakes

Group	Fresh AA6	MEAN INTAKE kgDM (83.35%)	ME 10.39MJ/kg DM
WC	10.65	8.90	92.47
CW	11.48	9.60	99.74
Mean	11.10	9.25	96.11

B. Energy values of Milk Constituents

Milk Butterfat	39.3J/g
Milk Protein	24.6J/g
Milk Lactose	16.0J/g

C. Efficiency of ME utilisation

Use of ME for lactation (K_L) 0.62

D. Calculation of ME Requirements

i) Maintenance ME

$M_{ME} = 0.51 MJ/kg^{0.75}$

ii) Concepta

$ME = 1.13\ e^{0.0106t}$
where e = 2.718
t = day since conception
At day 186[1] = 8.114 MJ
At day 198 = 9.215 MJ
At day 207 = 10.137 MJ
1. See also Section G later.

iii) **Activity Allowance**

10% Fasting Metabolism
FM (MJ/d) = 5.67 + 0.061W

Overall mean	Non-walking	3.3	(MJ/d)
	Walking	3.3	
Period I	Non-walking	3.3	
	Walking	3.2	
Period II	Non-walking	3.3	
	Walking	3.3	

iv) **Energy Cost of Walking**

Distance (horizontal) = 8.8km; (vertical) = 400m

	Energy Cost (Range) J/kg BWt/m		
	Low Speed	High Speed	Mean
Horizontal	1.92	2.26	2.09
Vertical	31.00	22.00	26.50

(from Ribeiro, Brockway and Webster, 1977)

		Mean cost of walking (MJ/d)			
	Mean BWt (kg)	Horizontal (880m)	Vertical (400m)	Total (MJ)	Daily Mean* (MJ)
Period I	427	7.85	4.53	12.38	8.84
Period II	456	8.39	4.83	13.22	9.44
Mean	442	8.13	4.69	12.82	9.16

*Animals walked for 5 days per week
Mean Daily Cost = Total Cost x $\frac{5}{7}$

E. Mean body weights and metabolic weights

	Period I		Period II	
Group	Weight (kg)	$W^{0.75}$ (kg)	Weight (kg)	$W^{0.75}$ (kg)
WC	427	93.93	449	97.54
CW	439	95.91	454	98.35

Mean non-walking weight = 444 kg ($W^{0.75}$ = 96.72)
Mean walking weight = 442 kg ($W^{0.75}$ = 96.23)

F. Mean increase in body weight

(See Figure 5.28. Section 5.4.1.)

		Kg
Period I	Control	0.76
	Walking	0.48
Period II	Control	1.62
	Walking	0.57
Overall Mean	Control	1.19
	Walking	0.52

G. *Stage of Pregnancy of cows*

After the completion of Experiment I, and when the cows had all calved, the cow records were consulted and the date of calving determined. From this date, the stage of pregnancy was calculated by working backwards to the beginning of the experiment. The dates of calving and the stage of pregnancy at the mid-point of each period and at the midpoint of the experiment (25.6.86) are given below:

Cow	Calving Date	Stage of Pregnancy (day) on: 14.6.86	25.6.86	5.7.86
8228	3.10.96	168	179	189
8125	10.9.86	191	202	212
8230	7.10.86	164	175	185
8143	2.9.86	199	210	220
8233	2.9.86	199	210	220
8122	11.9.86	190	201	211
Mean		185	196	206
8239	4.9.86	197	208	218
8221	10.9.86	191	202	212
8131	6.9.86	195	206	216
8146	1.9.86	190	201	211
8227	17.9.86	184	195	205
8234	8.10.86	161	172	182
Mean		186	197	207

EXPERIMENT II

The assumptions for Experiment II are as for Experiment I except where stated.

A. Concepta ME

Day of Gestation at Period mid-point:

Period I = 182
Period II = 203
Period III = 224

C_{ME} @ day 182 = 7.78 MJ/d
203 = 9.72 MJ/d
224 = 12.14 MJ/d

B. Activity ME

Period	I	AA6	3.7 (MJ/d)
		HS1	3.8
Period	II	AA6	3.8
		HS1	3.8
Period	III	AA6	3.9
		HS1	3.9

C. Exercise ME

		Energy Expenditure			
Diet	Body Weight (kg)	Horizontal (8800m)	Vertical (400)	Total (MJ)	Mean/day (MJ)
AA6	530	9.75	5.62	15.37	10.98
HS1	528	9.71	5.60	15.31	10.93

EXPERIMENT III

A. Feed Intake

In Experiment III animals were fed a flat rate of 4kg of one of three supplementary diets to *ad libitum* barley straw (Table 4.5). The mean calculated ME and CP contents for each supplement are given in Chapter Four (Table 4.5), and the mean straw intakes for each period for each group are given in Table 4.6 and below.

Period Means for Straw Intake (fresh and DM)

	Period I			Period II			Period III		
Diet	FW	DMC	DMI	FW	DMC	DMI	FW	DMC	DMI
HS2	4.06	866.1	3.52	4.60	856.8	3.94	5.32	858.5	4.57
DF	4.17	866.3	3.61	4.46	857.4	3.82	4.97	855.2	4.25
HP	4.52	864.0	3.91	5.06	853.1	4.32	5.65	853.3	4.82

FW = Fresh Weight (kg/d); DMC = Dry matter content (g/kg); DMI = Dry matter intake (kg/d)

The ME content of the straw was estimated to be 6.5MJ/kgDM (ESCA, 1982).

B. Concepta ME

The same requirements for growth of concepta used in Experiment II are used for Experiment III.

C. Exercise ME

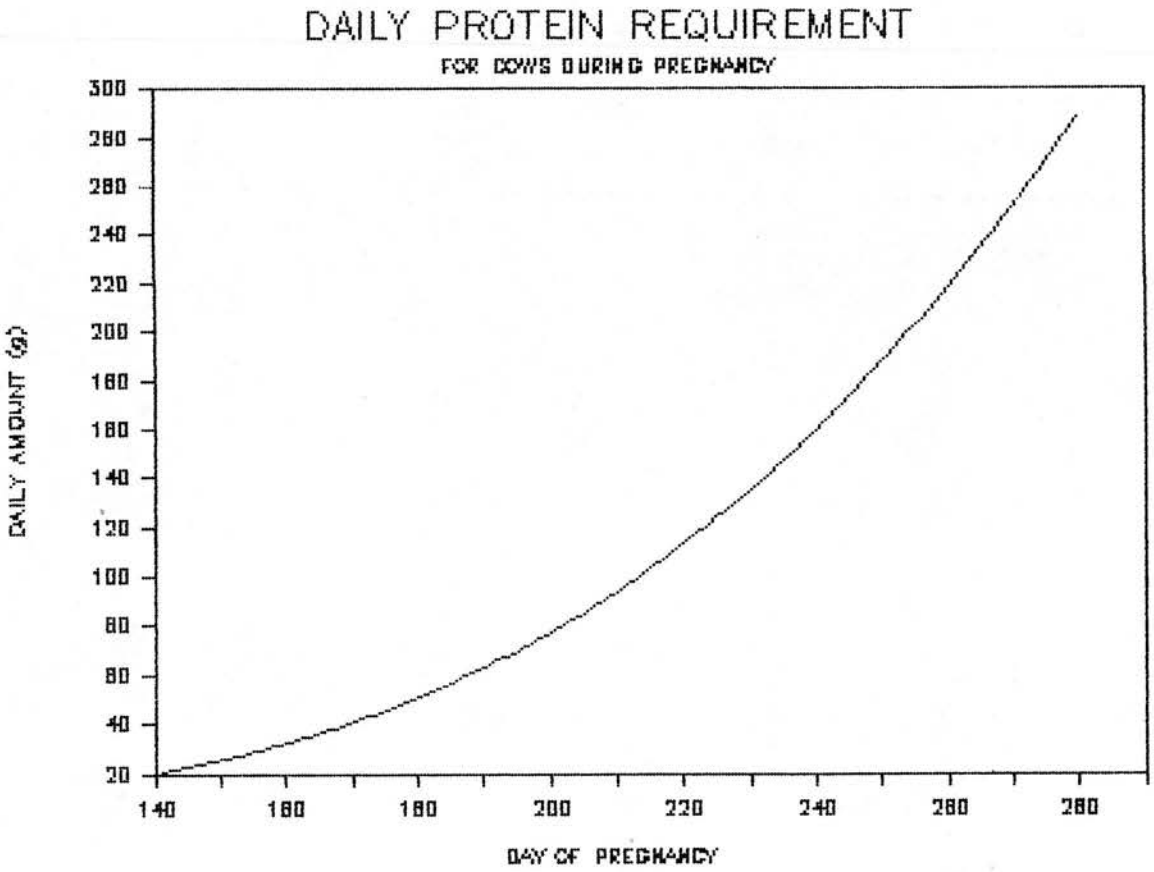
Diet	Body Weight (kg)	Energy Expenditure (MJ/d) Horizontal (10.6km)	Vertical (480M)	Total (MJ)	Mean/day (MJ)
HS2	493	10.92	6.27	17.19	12.28
DF	487	10.79	6.19	16.98	12.13
HP	520	11.52	6.61	18.13	12.95

EXAMPLE CALCULATION OF ENERGY BALANCES FOR EXPERIMENT I

Overall Non-walking Group Mean for Experiment I

Food Me = 90.66MJ
EVL Butterfat: 233 x 39.3 = 9156.9
Protein: 171 x 24.6 = 4206.6
Lactose: 348 x 16.0 = 5568.0
18931.5KJ
EVL = 18.93MJ
÷ 0.62
LME = 30.54MJ
Maintenance ME = 49.33MJ
Concepta ME = 9.215MJ (day 198)
Activity Allowance = 3.2754MJ
Total Expenditure = 92.36MJ

APPENDIX 8: DAILY PROTEIN REQUIREMENTS FOR GROWTH OF CONCEPTA (ARC,1980; TABLE 1.20)



APPENDIX 8C: CALCULATED GLUCOSE SUPPLY FROM PROPIONATE, AMINO ACIDS AND STARCH IN THE WALKING PERIOD IN EACH EXPERIMENT

Estimated glucose requirements for animals on each diet

Experiment	I	II	II	III	III	III
Diet	AA6	AA6	HS1	HS2	DF	HP
Milk Yield (kg)	5.26	6.45	7.57	4.28	2.48	3.65
Glucose Requirement (g)[1]	911.5	997.2	1077.8	841.0	711.4	795.6

1. Glucose Flux = 72 x Milk Yield + (370 x 1.44)

Estimation of propionate supplied by each diet and potential glucogenesis from propionate

Experiment	I	II	II	III	III	III
Diet	AA6	AA6	HS1	HS2	DF	HP
Digestibility %	66	66	70	60	70	60
DMI (kg)	9.3	10.6	9.6	7.6	7.5	8.0
DDM (kg)	6.1	7.0	6.7	4.6	5.3	4.8
Propionate (moles)	15.3	17.5	20.1	9.2	13.1	9.6
Glucose Produced (moles)	4.6	5.3	6.0	2.8	3.9	2.9
Glucose Produced (g)	823.5	945.0	1085.4	504.0	707.4	518.4
Glucose Required (g/d) (Table 6.9)	911.5	997.2	1077.8	841.0	711.4	795.6
Additional Glucose Required (g/d)	+88.0	+52.2	-7.6	-337.0	+4.0	-277.2

Estimation of protein supplied by each diet in Experiments I, II and III

Experiment	I	II	II	III	III	III
Diet	AA6	AA6	HS1	HS2	DF	HP
ME Intake (MJ)	96.1	110.1	108.4	69.4	61.7	64.1
RDP (ME x 8.4) (g)	807.3	924.8	910.6	583.0	518.3	538.4
RDP (dg x CP) (g)	1012.9	1213.9	1099.4	606.7	607.1	618.9
TMP Supplied[1]	439.2	503.1	495.4	317.2	281.9	292.9
UDP Supplied	337.6	404.7	366.5	132.5	132.0	771.3
Metabolisable Protein from UDP	229.6	275.2	249.2	90.1	89.8	524.5
Total Metabolisable Protein Supply (g)	668.8	778.3	744.6	407.3	371.7	817.4

1. From TMP = RDP (ME x 8.4) x 0.85 x 0.80 x 0.80

Protein requirements for animals on each diet in Experiments I, II and III

Experiment	I	II	II	III	III	III
Diet	AA6	AA6	HS1	HS2	DF	HP
Body Weight (kg)	441	530	528	493	487	521
$BWt^{0.75}$	96.2	110.5	110.1	104.6	103.7	109.1
Milk Yield (kg)	5.26	6.45	7.57	4.28	2.48	3.65
Milk Protein Content (g/kg)	29.7	36.7	38.0	30.4	34.4	41.1
Bodyweight Change	+0.5	-0.4	+0.2	-0.5	-0.2	-0.2
EUN	210.5	241.8	240.9	228.9	226.9	238.7
Hair	23.7	27.2	27.1	25.8	25.5	26.9
Milk	156.2	236.7	287.7	130.0	85.3	150.0
Growth	+75.0	-45.0	+30.0	-56.0	-22.0	-22.0
Growth Concepta	77.5	77.5	77.5	77.5	77.5	77.5
Total Requirement	542.9	538.2	663.1	406.2	393.2	471.1
Protein Supply (from previous Table)	668.8	778.3	744.6	407.3	371.7	817.4
Excess	125.9	240.1	81.5	1.1	0.0	346.3
Potential Glucose Supply (x 0.58)[1]	73.0	139.3	47.3	0.6	0.0	200.9

1. Assuming that all amino acids are glucogenic and are used for glucogenesis.

Summary of the potential glucose supply from propionate and amino acids from each diet in Experiments I, II and III

Experiment	I	II	II	III	III	III
Diet	AA6	AA6	HS1	HS2	DF	HP
Glucose Requirement (g/d)	911.5	997.2	1077.8	841.0	711.4	795.6
Maximum Glucose Supply from Propionate (g/d)	825.3	945.0	1085.4	504.0	707.4	518.4
Maximum Glucose Supply from Amino Acids (g/d)	73.0	139.3	47.3	0.6	0.0	200.9
Total Maximum Supply from these Sources	898.3	1084.3	1132.7	504.6	707.4	719.3
Additional Glucose Required (g/d)	(13.2)	(87.0)	(54.9)	336.4	4.0	76.3

Figures in brackets are in excess of requirement

Starch supply to the small intestine and the potential glucose production from this for each diet

Experiment	I	II	II	III	III	III
Diet	AA6	AA6	HS1	HS2	DF	HP
Starch Content (g/kgDM)	202	202	300	525	224	130
Duodenal Starch (g/kgDM)	20.2	20.2	30.0	146.9	22.4	13.0
Total Duodenal Supply (g/d)	186.9	214.1	228.0	528.8	80.4	46.9
Pre-Caecal Digestion	140.2	160.6	171.0	396.6	60.3	35.2
Balance from Pr + AAs	+13.2	+87.0	+54.9	-336.4	-4.0	-76.3
Final Balance	+153.4	+247.6	+225.9	+60.2	+56.3	-41.1

APPENDIX 9A: FULL DATA FOR MILK YIELDS, MILK CONSTITUENT YIELDS AND MILK CONSTITUENT CONTENTS (%) FOR EXPERIMENT I

The data are presented in the following format:

Cows 1 to 6 (GROUP II RESTING) for each day of the first period (21 days; 126 values)

Cows 7 to 12 (GROUP I WALKING) for each day of the first period (21 days; 126 values)

Cows 7 to 12 (GROUP I RESTING) for each day of the second period (21 days; 126 values)

Cows 1 to 6 (GROUP II WALKING) for each day of the second period (21 days; 126 values)

TOTAL 504 Values

Nine columns of data are presented: Milk Yield (kg), Milk Fat %, Milk Solids Not Fat %, Milk Protein %, Milk Fat Yield (g/d), Milk Solids Not Fat Yield (g/d), Milk Protein Yield (g/d), Lactose %, and Lactose Yield (g/d).

ROW	MY	F%	SNF%	P%	BF	SNF	P	L%	L
1	4.0	2.60	9.14	3.5	104.00	365.60	140.0	5.64000	225.600
2	7.5	4.85	8.12	2.5	363.75	609.00	187.5	5.62000	421.500
3	7.9	4.75	8.82	3.1	375.25	696.78	244.9	5.72000	451.880
4	8.5	4.50	8.46	2.9	382.50	719.10	246.5	5.56000	472.600
5	9.2	4.70	8.43	3.1	432.40	775.56	285.2	5.33000	490.360
6	7.5	3.45	8.55	3.4	258.75	641.25	255.0	5.15000	386.250
7	2.5	4.90	9.30	2.5	122.50	232.50	62.5	6.80000	170.000
8	7.3	5.10	8.94	2.9	372.30	652.62	211.7	6.04000	440.920
9	7.3	4.55	9.02	3.0	332.15	658.46	219.0	6.01999	439.460
10	8.6	3.75	8.60	2.7	322.50	739.60	232.2	5.90000	507.400
11	8.5	3.85	8.77	3.3	327.25	745.45	280.5	5.47000	464.950
12	6.7	3.45	8.73	2.9	231.15	584.91	194.3	5.82999	390.610
13	2.5	4.12	9.31	2.7	103.00	232.75	67.5	6.61000	165.250
14	8.1	4.95	8.52	2.3	400.95	690.12	186.3	6.22000	503.820
15	8.0	3.80	9.21	2.9	304.00	736.80	232.0	6.31000	504.800
16	9.2	4.60	8.71	2.8	423.20	801.32	257.6	5.91000	543.720
17	9.0	4.53	8.73	2.9	407.70	785.70	261.0	5.83000	524.700
18	7.2	3.78	8.77	2.9	272.16	631.44	208.8	5.87000	422.640
19	3.3	4.50	8.86	3.4	148.50	292.38	112.2	5.46000	180.180
20	7.7	2.35	8.34	2.5	180.95	642.18	192.5	5.83999	449.680
21	7.9	2.85	8.60	2.5	225.15	679.40	197.5	6.09999	481.900
22	8.2	5.50	9.25	2.9	451.00	758.50	237.8	6.34999	520.700
23	8.3	2.50	8.47	2.3	207.50	703.01	190.9	6.16999	512.110
24	6.9	3.35	8.56	2.4	231.15	590.64	165.6	6.16000	425.040
25	3.5	5.75	9.49	3.0	201.25	332.15	105.0	6.49000	227.150
26	8.2	5.05	8.91	3.4	414.10	730.62	278.8	5.51000	451.820
27	7.4	3.35	9.59	2.7	247.90	709.66	199.8	6.88999	509.860
28	7.9	4.70	8.95	2.9	371.30	707.05	229.1	6.05000	477.950
29	8.6	4.35	9.03	3.0	374.10	776.58	258.0	6.03000	518.580
30	7.0	4.10	8.99	2.6	287.00	629.30	182.0	6.39000	447.300
31	3.3	3.80	8.14	3.5	125.40	268.62	115.5	4.63999	153.120
32	8.8	3.60	8.54	2.6	316.80	751.52	228.8	5.94000	522.720
33	8.3	4.75	8.77	3.2	394.25	727.91	265.6	5.57000	462.310
34	8.5	3.65	8.52	3.2	310.25	724.20	272.0	5.32000	452.200
35	8.7	3.50	8.57	2.8	304.50	745.59	243.6	5.77000	501.990
36	7.4	3.50	8.54	2.2	259.00	631.96	162.8	6.33999	469.160
37	3.4	5.18	9.54	3.6	176.12	324.36	122.4	5.94000	201.960
38	8.3	4.28	8.85	3.3	355.24	734.55	273.9	5.55000	460.650
39	7.0	3.80	9.35	2.9	266.00	654.50	203.0	6.45000	451.500
40	7.7	4.40	8.89	3.0	338.80	684.53	231.0	5.89000	453.530
41	7.8	4.13	9.01	2.9	322.14	702.78	226.2	6.11000	476.580
42	7.1	3.65	8.87	2.6	259.15	629.77	184.6	6.26999	445.170
43	3.6	5.80	9.48	4.0	208.80	341.28	144.0	5.47999	197.280
44	8.4	3.50	8.87	2.8	294.00	745.08	235.2	6.07000	509.880
45	7.1	3.65	9.02	3.3	259.15	640.42	234.3	5.72000	406.120
46	7.6	4.00	8.95	3.4	304.00	680.20	258.4	5.55000	421.800
47	8.0	3.95	8.77	2.6	316.00	701.60	208.0	6.16999	493.600
48	7.1	3.35	8.81	3.0	237.85	625.51	213.0	5.81000	412.510
49	3.3	4.60	9.58	4.2	151.80	316.14	138.6	5.38000	177.540
50	8.2	3.50	8.79	3.1	287.00	720.78	254.2	5.68999	466.580
51	7.2	4.05	9.11	3.1	291.60	655.92	223.2	6.01000	432.720
52	7.4	4.10	8.82	3.1	303.40	652.68	229.4	5.72000	423.280
53	7.4	3.90	8.98	2.8	288.60	664.52	207.2	6.18000	457.320
54	7.1	3.20	8.75	2.6	227.20	621.25	184.6	6.15000	436.650
55	3.4	4.05	9.48	3.7	137.70	322.32	125.8	5.77999	196.520
56	8.2	3.50	8.64	2.6	287.00	708.48	213.2	6.04000	495.280
57	6.9	3.35	8.96	2.8	231.15	618.24	193.2	6.16000	425.040
58	6.8	4.15	8.90	3.0	282.20	605.20	204.0	5.89999	401.200
59	7.4	4.00	8.93	2.8	296.00	660.82	207.2	6.13000	453.620

Row	MY	F%	SNF%	P%	BF	SNF	P	L%	L
60	7.3	3.20	8.70	2.5	233.60	635.10	182.5	6.20000	452.600
61	3.5	4.15	9.38	3.6	145.25	328.30	126.0	5.77999	202.300
62	8.5	3.70	8.65	2.3	314.50	735.25	195.5	6.35000	539.750
63	7.2	3.80	8.69	2.7	273.60	625.68	194.4	5.99000	431.280
64	7.2	3.85	8.75	3.0	277.20	630.00	216.0	5.75000	414.000
65	7.6	3.50	8.90	2.7	266.00	676.40	205.2	6.20000	471.200
66	7.1	3.25	8.64	2.1	230.75	613.44	149.1	6.54000	464.340
67	3.1	5.15	9.50	3.6	159.65	294.50	111.6	5.89999	182.900
68	8.0	3.70	8.65	2.5	296.00	692.00	200.0	6.15000	492.000
69	7.6	4.45	9.05	3.2	338.20	687.80	243.2	5.85000	444.600
70	7.3	3.95	8.94	3.6	288.35	652.62	262.8	5.34000	389.820
71	7.3	3.45	8.98	2.9	251.85	655.54	211.7	6.08000	443.840
72	7.2	3.35	8.69	2.3	241.20	625.68	165.6	6.39000	460.080
73	3.3	5.15	9.23	3.7	169.95	304.59	122.1	5.52999	182.490
74	7.9	3.40	8.69	2.3	268.60	686.51	181.7	6.38999	504.810
75	7.2	3.90	9.08	2.1	280.80	653.76	151.2	6.97999	502.560
76	7.3	4.05	8.79	3.1	295.65	641.67	226.3	5.69000	415.370
77	7.6	3.70	8.90	2.6	281.20	676.40	197.6	6.30000	478.800
78	7.1	3.30	8.80	2.7	234.30	624.80	191.7	6.09999	433.100
79	3.0	4.30	9.35	3.7	129.00	280.50	111.0	5.64999	169.500
80	7.9	4.00	8.75	2.8	316.00	691.25	221.2	5.95000	470.050
81	7.2	3.70	9.20	3.0	266.40	662.40	216.0	6.20000	446.400
82	6.7	4.00	9.10	3.2	268.00	609.70	214.4	5.90000	395.300
83	7.0	3.55	8.83	2.2	248.50	618.10	154.0	6.63000	464.100
84	7.3	3.55	8.75	2.7	259.15	638.75	197.1	6.05000	441.650
85	2.9	3.95	9.44	3.2	114.55	273.76	92.8	6.23999	180.960
86	7.8	3.35	8.86	2.7	261.30	691.08	210.6	6.16000	480.480
87	6.6	3.50	9.11	3.1	231.00	601.26	204.6	6.00999	396.660
88	7.1	4.20	8.87	3.0	298.20	629.77	213.0	5.87000	416.770
89	7.6	3.35	8.94	2.7	254.60	679.44	205.2	6.24000	474.240
90	7.3	3.95	8.84	2.8	288.35	645.32	204.4	6.04000	440.920
91	3.2	5.20	9.16	3.7	166.40	293.12	118.4	5.46000	174.720
92	7.9	3.60	8.84	2.9	284.40	698.36	229.1	5.93999	469.260
93	7.2	4.70	9.07	3.0	338.40	653.04	216.0	6.07000	437.040
94	6.9	4.00	8.82	3.2	276.00	608.58	220.8	5.62000	387.780
95	7.6	3.80	8.94	2.9	288.80	679.44	220.4	6.03999	459.040
96	7.3	3.50	8.69	2.6	255.50	634.37	189.8	6.09000	444.570
97	2.8	4.10	9.12	2.9	114.80	255.36	81.2	6.22000	174.160
98	7.9	4.25	8.78	2.7	335.75	693.62	213.3	6.07999	480.320
99	7.1	4.20	9.02	3.1	298.20	640.42	220.1	5.92000	420.320
100	6.7	4.40	8.82	3.4	294.80	590.94	227.8	5.42000	363.140
101	7.2	3.70	8.93	3.1	266.40	642.96	223.2	5.83000	419.760
102	7.4	4.00	8.75	3.4	296.00	647.50	251.6	5.34999	395.900
103	3.1	4.65	8.97	3.1	144.15	278.07	96.1	5.86999	181.970
104	7.9	3.70	8.60	2.5	292.30	679.40	197.5	6.09999	481.900
105	7.1	3.65	9.20	2.8	259.15	653.20	198.8	6.39999	454.400
106	6.5	4.10	8.95	2.8	266.50	581.75	182.0	6.14999	399.750
107	7.9	3.55	8.87	2.9	280.45	700.73	229.1	5.96999	471.630
108	6.9	3.60	8.71	2.5	248.40	600.99	172.5	6.21000	428.490
109	3.2	4.85	8.92	3.0	155.20	285.44	96.0	5.91999	189.440
110	7.5	3.45	8.76	3.5	258.75	657.00	262.5	5.26000	394.500
111	6.6	3.75	9.05	3.2	247.50	597.30	211.2	5.85000	386.100
112	6.0	4.20	8.92	3.5	252.00	535.20	210.0	5.41999	325.200
113	7.4	3.75	8.65	2.6	277.50	640.10	192.4	6.05000	447.700
114	7.0	3.90	8.60	2.6	273.00	602.00	182.0	6.00000	420.000
115	3.2	4.40	9.04	3.2	140.80	289.28	102.4	5.83999	186.880
116	8.1	3.60	8.75	3.0	291.60	708.75	243.0	5.75000	465.750
117	7.3	4.30	9.17	2.9	313.90	669.41	211.7	6.27000	457.710
118	6.1	4.15	9.01	3.3	253.15	549.61	201.3	5.71000	348.310
119	7.4	3.85	8.46	2.8	284.90	626.04	207.2	5.66000	418.840
120	7.4	3.65	8.80	2.5	270.10	651.20	185.0	6.30000	466.200

Row	MY	F%	SNF%	P%	BF	SNF	P	L%	L
121	3.2	4.15	9.12	3.3	132.80	291.84	105.6	5.81999	186.240
122	7.4	3.20	8.83	3.1	236.80	653.42	229.4	5.73000	424.020
123	7.0	4.10	9.06	3.0	287.00	634.20	210.0	6.06000	424.200
124	6.3	3.95	9.04	3.5	248.85	569.52	220.5	5.53999	349.020
125	6.9	3.75	8.62	2.9	258.75	594.78	200.1	5.71999	394.680
126	6.9	3.80	8.83	2.7	262.20	609.27	186.3	6.13000	422.970
127	3.3	2.50	8.75	2.6	82.50	288.75	85.8	6.15000	202.950
128	7.1	3.75	8.22	2.7	266.25	583.62	191.7	5.51999	391.920
129	8.0	3.20	8.12	2.7	256.00	649.60	216.0	5.42000	433.600
130	6.1	4.10	8.60	3.3	250.10	524.60	201.3	5.30000	323.300
131	7.6	4.55	8.92	3.3	345.80	677.92	250.8	5.62000	427.120
132	8.0	3.45	8.66	3.0	276.00	692.80	240.0	5.66000	452.800
133	4.1	3.80	9.01	3.4	155.80	369.41	139.4	5.61000	230.010
134	5.6	5.30	8.49	2.6	296.80	475.44	145.6	5.88999	329.840
135	7.1	4.30	8.50	2.8	305.30	603.50	198.8	5.70000	404.700
136	5.0	5.30	8.14	2.9	265.00	407.00	145.0	5.23999	262.000
137	6.6	4.35	9.20	3.3	287.10	607.20	217.8	5.90000	389.400
138	7.5	4.10	9.02	2.9	307.50	676.50	217.5	6.12000	459.000
139	2.3	3.80	8.80	2.7	87.40	202.40	62.1	6.09999	140.300
140	6.3	4.60	8.51	2.4	289.80	536.13	151.2	6.10999	384.930
141	7.0	3.55	8.46	2.7	248.50	592.20	189.0	5.75999	403.200
142	4.9	4.73	8.69	2.8	231.77	425.81	137.2	5.88999	288.610
143	6.8	4.58	9.09	2.7	311.44	618.12	183.6	6.39000	434.520
144	7.5	4.05	8.89	2.8	303.75	666.75	210.0	6.09000	456.750
145	4.6	3.15	8.24	2.2	144.90	379.04	101.2	6.03999	277.840
146	6.1	2.90	7.98	2.4	176.90	486.78	146.4	5.57999	340.380
147	6.9	2.50	8.35	2.4	172.50	576.15	165.6	5.95000	410.550
148	5.6	5.85	8.84	3.0	327.60	495.04	168.0	5.83999	327.040
149	6.9	2.70	8.74	2.6	186.30	603.06	179.4	6.14000	423.660
150	7.3	2.75	8.43	2.7	200.75	615.39	197.1	5.73000	418.290
151	4.7	5.10	8.84	2.8	239.70	415.48	131.6	6.03999	283.880
152	6.8	5.45	8.90	2.8	370.60	605.20	190.4	6.09999	414.800
153	7.7	3.90	8.80	2.6	300.30	677.60	200.2	6.20000	477.400
154	6.1	5.35	8.78	3.1	326.35	535.58	189.1	5.67999	346.480
155	7.1	4.60	9.25	2.9	326.60	656.75	205.9	6.35000	450.850
156	7.0	4.65	9.12	2.7	325.50	638.40	189.0	6.42000	449.400
157	4.7	3.60	8.45	2.7	169.20	397.15	126.9	5.74999	270.250
158	6.9	5.40	8.29	2.9	372.60	572.01	200.1	5.38999	371.910
159	7.3	3.50	8.32	2.5	255.50	607.36	182.5	5.82000	424.860
160	6.1	4.45	8.40	2.9	271.45	512.40	176.9	5.50000	335.500
161	6.6	4.10	9.07	3.0	270.60	598.62	198.0	6.07000	400.620
162	6.8	4.15	8.96	3.1	282.20	609.28	210.8	5.85999	398.480
163	5.0	3.48	8.55	2.9	174.00	427.50	145.0	5.65000	282.500
164	5.9	4.10	8.48	2.8	241.90	500.32	165.2	5.68000	335.120
165	6.9	3.40	8.50	2.7	234.60	586.50	186.3	5.80000	400.200
166	5.4	5.58	8.55	3.2	301.32	461.70	172.8	5.34999	288.900
167	7.1	3.53	9.24	3.0	250.63	656.04	213.0	6.24000	443.040
168	5.8	4.93	9.07	3.1	285.94	526.06	179.8	5.96999	346.260
169	3.8	3.40	8.65	3.1	129.20	328.70	117.8	5.55000	210.900
170	5.7	5.55	8.67	2.7	316.35	494.19	153.9	5.96999	340.290
171	6.4	3.70	8.68	2.9	236.80	555.52	185.6	5.78000	369.920
172	5.5	5.45	8.70	3.5	299.75	478.50	192.5	5.20000	286.000
173	6.4	5.50	9.41	3.0	352.00	602.24	192.0	6.41000	410.240
174	5.5	5.70	9.17	3.1	313.50	504.35	170.5	6.07000	333.850
175	4.6	4.20	8.67	3.1	193.20	398.82	142.6	5.56999	256.220
176	5.4	5.30	8.69	2.7	286.20	469.26	145.8	5.98999	323.460
177	6.5	3.45	8.81	2.8	224.25	572.65	182.0	6.01000	390.650
178	5.5	4.70	8.80	2.3	258.50	484.00	126.5	6.50000	357.500
179	6.0	4.20	9.19	3.3	252.00	551.40	198.0	5.88999	353.400
180	5.1	4.80	9.28	3.1	244.80	473.28	158.1	6.17999	315.180
181	4.7	3.80	8.66	3.5	178.60	407.02	164.5	5.16000	242.520

Row	MY	F%	SNF%	P%	BF	SNF	P	L%	L
182	5.5	4.80	8.70	2.8	264.00	478.50	154.0	5.89999	324.500
183	6.4	3.25	8.64	5.7	208.00	552.96	364.8	2.94000	188.160
184	5.3	4.65	8.70	2.8	246.45	461.10	148.4	5.89999	312.700
185	6.2	3.95	9.06	2.7	244.90	561.72	167.4	6.36000	394.320
186	5.5	4.35	9.15	3.4	239.25	503.25	187.0	5.75000	316.250
187	4.8	4.00	8.66	3.2	192.00	415.68	153.6	5.46000	262.080
188	6.1	4.05	8.26	2.5	247.05	503.86	152.5	5.76000	351.360
189	7.0	2.70	8.56	2.9	189.00	599.20	203.0	5.66000	396.200
190	5.7	3.65	8.67	2.8	208.05	494.19	159.6	5.86999	334.590
191	6.7	3.50	8.89	3.2	234.50	595.63	214.4	5.69000	381.230
192	5.5	4.00	9.08	3.0	220.00	499.40	165.0	6.07999	334.400
193	4.9	3.90	8.66	2.8	191.10	424.34	137.2	5.85999	287.140
194	6.7	4.30	8.52	2.4	288.10	570.84	160.8	6.12000	410.040
195	7.3	2.95	8.87	1.6	215.35	647.51	116.8	7.26999	530.710
196	6.2	4.15	8.76	2.5	257.30	543.12	155.0	6.26000	388.120
197	6.9	3.80	9.04	2.7	262.20	623.76	186.3	6.33999	437.460
198	5.6	4.10	9.07	2.7	229.60	507.92	151.2	6.36999	356.720
199	4.4	3.95	8.66	2.9	173.80	381.04	127.6	5.76000	253.440
200	6.5	3.90	8.33	2.3	253.50	541.45	149.5	6.02999	391.950
201	7.0	2.95	8.60	2.7	206.50	602.00	189.0	5.89999	413.000
202	5.5	3.90	8.73	3.1	214.50	480.15	170.5	5.62999	309.650
203	6.3	4.05	8.76	2.8	255.15	551.88	176.4	5.95999	375.480
204	5.2	4.25	9.24	2.1	221.00	480.48	109.2	7.13999	371.280
205	4.2	4.13	8.52	3.0	173.46	357.84	126.0	5.52000	231.840
206	6.7	4.20	8.39	2.8	281.40	562.13	187.6	5.59000	374.530
207	7.2	2.90	8.51	1.2	208.80	612.72	86.4	7.30999	526.320
208	5.4	4.35	8.55	2.9	234.90	461.70	156.6	5.64999	305.100
209	5.2	4.35	9.18	3.1	226.20	477.36	161.2	6.08000	316.160
210	4.7	4.25	9.24	1.0	199.75	434.28	47.0	8.23999	387.280
211	4.2	4.30	8.37	3.0	180.60	351.54	126.0	5.37000	225.540
212	5.9	4.65	8.49	2.9	274.35	500.91	171.1	5.59000	329.810
213	6.8	3.15	8.61	2.6	214.20	585.48	176.8	6.00999	408.680
214	5.2	4.00	8.68	3.2	208.00	451.36	166.4	5.48000	284.960
215	5.1	4.35	9.28	3.4	221.85	473.28	173.4	5.87999	299.880
216	3.5	4.65	9.39	3.5	162.75	328.65	122.5	5.89000	206.150
217	4.3	3.85	8.60	2.8	165.55	369.80	120.4	5.79999	249.400
218	5.9	4.55	9.05	3.3	268.45	533.95	194.7	5.75000	339.250
219	7.2	3.10	8.25	2.5	223.20	594.00	180.0	5.75000	414.000
220	5.2	4.25	8.74	3.1	221.00	454.48	161.2	5.63999	293.280
221	5.2	4.40	9.24	3.9	228.80	480.48	202.8	5.33999	277.680
222	3.5	4.70	9.53	3.3	164.50	333.55	115.5	6.22999	218.050
223	3.6	2.60	8.49	2.7	93.60	305.64	97.2	5.79000	208.440
224	5.8	4.40	8.49	2.7	255.20	492.42	156.6	5.78999	335.820
225	7.4	3.10	8.48	2.6	229.40	627.52	192.4	5.88000	435.120
226	5.5	4.15	8.68	2.9	228.25	477.40	159.5	5.78000	317.900
227	5.4	3.45	8.90	3.4	186.30	480.60	183.6	5.50000	297.000
228	3.7	4.70	9.28	3.4	173.90	343.36	125.8	5.87999	217.560
229	4.1	3.70	8.43	2.9	151.70	345.63	118.9	5.52999	226.730
230	5.7	4.20	8.47	2.6	239.40	482.79	148.2	5.86999	334.590
231	7.5	2.90	8.44	2.4	217.50	633.00	180.0	6.04000	453.000
232	5.5	3.75	8.63	2.9	206.25	474.65	159.5	5.73000	315.150
233	5.7	3.95	8.97	2.7	225.15	511.29	153.9	6.26999	357.390
234	3.6	3.90	9.08	3.1	140.40	326.88	111.6	5.98000	215.280
235	4.1	4.10	8.17	2.8	168.10	334.97	114.8	5.36999	220.170
236	6.2	3.45	8.24	2.7	213.90	510.88	167.4	5.53999	343.480
237	7.5	3.15	8.14	2.9	236.25	610.50	217.5	5.24000	393.000
238	5.9	3.80	8.51	2.7	224.20	502.09	159.3	5.81000	342.790
239	6.1	4.30	8.65	2.9	262.30	527.65	176.9	5.75000	350.750
240	4.0	4.50	9.42	3.4	180.00	376.80	136.0	6.01999	240.800
241	3.8	3.20	8.07	2.5	121.60	306.66	95.0	5.57000	211.660
242	6.0	4.30	8.25	2.7	258.00	495.00	162.0	5.55000	333.000

Row	MY	F%	SNF	P%	BF	SNF	P	L%	L
243	7.3	3.70	8.56	2.7	270.10	624.88	197.1	5.86000	427.780
244	5.6	4.30	8.67	3.1	240.80	485.52	173.6	5.57000	311.920
245	5.3	4.10	9.12	2.8	217.30	483.36	148.4	6.31999	334.960
246	3.9	4.70	9.32	3.2	183.30	363.48	124.8	6.11999	238.680
247	3.8	3.10	8.12	2.7	117.80	308.56	102.6	5.41999	205.960
248	5.6	4.25	8.28	2.8	238.00	463.68	156.8	5.48000	306.880
249	7.2	4.00	8.62	2.8	288.00	620.64	201.6	5.82000	419.040
250	5.1	4.10	8.71	3.2	209.10	444.21	163.2	5.50999	281.010
251	4.8	4.30	9.12	3.0	206.40	437.76	144.0	6.12000	293.760
252	3.7	4.50	9.25	2.9	166.50	342.25	107.3	6.34999	234.950
253	4.0	4.00	8.43	2.4	160.00	337.20	96.0	6.03000	241.200
254	5.9	4.80	8.33	2.7	283.20	491.47	159.3	5.62999	332.170
255	7.3	3.50	8.52	2.5	255.50	621.96	182.5	6.02000	439.460
256	5.4	4.60	8.66	2.8	248.40	467.64	151.2	5.85999	316.440
257	5.1	4.60	9.08	3.1	234.60	463.08	158.1	5.97999	304.980
258	4.2	4.65	9.39	3.1	195.30	394.38	130.2	6.28999	264.180
259	3.8	4.10	8.27	2.6	155.80	314.26	98.8	5.66999	215.460
260	6.2	4.20	8.37	2.6	260.40	518.94	161.2	5.77000	357.740
261	7.4	3.20	8.35	2.6	236.80	617.90	192.4	5.75000	425.500
262	5.7	4.00	8.67	2.7	228.00	494.19	153.9	5.96999	340.290
263	5.6	4.00	8.95	1.9	224.00	501.20	106.4	7.05000	394.800
264	4.0	4.05	9.31	3.0	162.00	372.40	120.0	6.31000	252.400
265	4.5	4.20	8.19	2.1	189.00	368.55	94.5	6.08999	274.050
266	6.7	4.20	8.49	2.7	281.40	568.83	180.9	5.78999	387.930
267	7.7	3.25	8.64	2.7	250.25	665.28	207.9	5.93999	457.380
268	5.9	3.80	8.74	3.1	224.20	515.66	182.9	5.64000	332.760
269	6.0	3.90	9.03	3.3	234.00	541.80	198.0	5.73000	343.800
270	4.1	4.05	9.36	3.4	166.05	383.76	139.4	5.95999	244.360
271	4.6	3.70	8.23	2.6	170.20	378.58	119.6	5.62999	258.980
272	6.6	4.80	8.28	2.6	316.80	546.48	171.6	5.67999	374.880
273	7.6	3.20	8.60	2.7	243.20	653.60	205.2	5.90000	448.400
274	5.8	3.70	8.53	3.0	214.60	494.74	174.0	5.53000	320.740
275	5.7	3.65	8.79	3.1	208.05	501.03	176.7	5.68999	324.330
276	4.1	3.95	9.24	3.4	161.95	378.84	139.4	5.83999	239.440
277	4.5	3.20	8.27	2.9	144.00	372.15	130.5	5.37000	241.650
278	6.5	3.85	8.27	2.7	250.25	537.55	175.5	5.57000	362.050
279	7.8	2.85	8.58	2.8	222.30	669.24	218.4	5.77999	450.840
280	5.8	3.40	8.89	3.1	197.20	515.62	179.8	5.79000	335.820
281	5.3	3.55	9.00	3.2	188.15	477.00	169.6	5.79999	307.400
282	3.8	3.75	9.35	3.4	142.50	355.30	129.2	5.94999	226.100
283	4.0	3.20	8.30	3.0	128.00	332.00	120.0	5.29999	212.000
284	6.4	4.10	8.22	2.7	262.40	526.08	172.8	5.52000	353.280
285	7.6	3.05	8.49	2.8	231.80	645.24	212.8	5.68999	432.440
286	5.5	3.75	8.48	3.1	206.25	466.40	170.5	5.37999	295.900
287	5.4	3.80	8.89	3.3	205.20	480.06	178.2	5.59000	301.860
288	3.6	4.15	9.25	3.6	149.40	333.00	129.6	5.65000	203.400
289	4.4	3.50	8.57	3.1	154.00	377.08	136.4	5.47000	240.680
290	6.4	4.70	8.27	2.5	300.80	529.28	160.0	5.77000	369.280
291	7.4	3.15	8.51	2.7	233.10	629.74	199.8	5.81000	429.940
292	5.6	3.55	9.03	3.1	198.80	505.68	173.6	5.93000	332.080
293	5.4	3.75	8.93	3.3	202.50	482.22	178.2	5.63000	304.020
294	3.7	3.95	9.41	3.6	146.15	348.17	133.2	5.80999	214.970
295	4.2	3.55	8.33	2.8	149.10	349.86	117.6	5.52999	232.260
296	6.0	3.85	8.40	2.4	231.00	504.00	144.0	6.00000	360.000
297	7.4	2.75	8.63	2.6	203.50	638.62	192.4	6.02999	446.220
298	5.3	3.55	8.77	3.1	188.15	464.81	164.3	5.66999	300.510
299	5.1	3.65	8.85	3.3	186.15	451.35	168.3	5.55000	283.050
300	3.4	3.90	9.53	3.6	132.60	324.02	122.4	5.92999	201.620
301	4.0	3.90	8.45	2.8	156.00	338.00	112.0	5.64999	226.000
302	6.1	4.20	8.37	2.6	256.20	510.57	158.6	5.76999	351.970
303	7.1	3.25	8.51	2.7	230.75	604.21	191.7	5.80999	412.510

Row	MY	F%	SNF%	L%	BF	SNF	P	L%	L
304	5.6	4.50	8.94	2.7	252.00	500.64	151.2	6.23999	349.440
305	5.1	4.20	8.01	3.1	214.20	408.51	158.1	4.90999	250.410
306	3.3	4.40	9.61	3.4	145.20	317.13	112.2	6.21000	204.930
307	3.5	2.95	8.42	2.9	103.25	294.70	101.5	5.51999	193.200
308	6.0	4.55	8.57	2.7	273.00	514.20	162.0	5.87000	352.200
309	6.9	3.35	8.59	2.6	231.15	592.71	179.4	5.99000	413.310
310	5.4	4.05	8.73	3.0	218.70	471.42	162.0	5.72999	309.420
311	5.1	4.20	8.99	3.1	214.20	458.49	158.1	5.89000	300.390
312	3.2	4.85	9.60	3.6	155.20	307.20	115.2	5.99999	192.000
313	3.9	3.95	8.29	2.8	154.05	323.31	109.2	5.48999	214.110
314	5.9	4.25	8.54	2.7	250.75	503.86	159.3	5.84000	344.560
315	6.7	3.35	8.54	2.6	224.45	572.18	174.2	5.93999	397.979
316	5.5	4.35	8.80	2.7	239.25	484.00	148.5	6.09999	335.500
317	5.2	4.15	9.08	3.2	215.80	472.16	166.4	5.87999	305.760
318	3.2	4.85	9.44	3.4	155.20	302.08	108.8	6.03999	193.280
319	2.7	3.80	8.54	2.8	102.60	230.58	75.6	5.73999	154.980
320	5.9	4.25	8.61	2.9	250.75	507.99	171.1	5.71000	336.890
321	6.9	3.20	8.62	2.0	220.80	594.78	138.0	6.62000	456.780
322	5.4	4.10	8.85	2.8	221.40	477.90	151.2	6.04999	326.700
323	5.2	3.85	9.07	3.3	200.20	471.64	171.6	5.76999	300.040
324	3.2	4.70	9.68	3.5	150.40	309.76	112.0	6.17999	197.760
325	3.4	4.25	8.46	3.0	144.50	287.64	102.0	5.46000	185.640
326	5.8	4.35	8.53	2.6	252.30	494.74	150.8	5.93000	343.940
327	6.5	3.25	8.64	3.2	211.25	561.60	208.0	5.44000	353.600
328	5.2	4.00	8.80	3.0	208.00	457.60	156.0	5.80000	301.600
329	5.6	3.95	8.99	3.0	221.20	503.44	168.0	5.99000	335.440
330	3.0	4.35	9.25	3.5	130.50	277.50	105.0	5.75000	172.500
331	2.9	4.45	8.38	3.1	129.05	243.02	89.9	5.27999	153.120
332	5.7	4.65	8.66	2.9	265.05	493.62	165.3	5.75999	328.320
333	6.5	3.75	8.65	2.9	243.75	562.25	188.5	5.75000	373.750
334	5.2	4.08	8.76	2.8	212.16	455.52	145.6	5.95999	309.920
335	4.9	3.90	8.95	3.1	191.10	438.55	151.9	5.84999	286.650
336	2.9	4.85	9.56	3.7	140.65	277.24	107.3	5.85999	169.940
337	2.4	4.05	8.51	2.5	97.20	204.24	60.0	6.01000	144.240
338	5.9	4.45	8.37	2.8	262.55	493.83	165.2	5.57000	328.630
339	6.6	3.30	8.53	2.7	217.80	562.98	178.2	5.83000	384.780
340	5.1	4.15	8.85	2.9	211.65	451.35	147.9	5.94999	303.450
341	4.8	4.05	9.09	3.4	194.40	436.32	163.2	5.69000	273.120
342	2.8	4.95	9.59	3.6	138.60	268.52	100.8	5.98999	167.720
343	3.0	5.10	8.61	2.9	153.00	258.30	87.0	5.70999	171.300
344	5.7	4.85	8.72	2.7	276.45	497.04	153.9	6.01999	343.140
345	6.2	3.40	8.75	2.6	210.80	542.50	161.2	6.15000	381.300
346	4.9	4.20	8.81	2.9	205.80	431.69	142.1	5.90999	289.590
347	5.0	4.55	9.12	3.2	227.50	456.00	160.0	5.91999	296.000
348	2.7	5.10	9.79	3.7	137.70	264.33	99.9	6.08999	164.430
349	3.2	3.90	8.53	3.2	124.80	272.96	102.4	5.32999	170.560
350	5.7	4.75	8.65	3.1	270.75	493.05	176.7	5.54999	316.350
351	6.1	3.45	8.75	2.9	210.45	533.75	176.9	5.85000	356.850
352	5.0	4.10	8.82	3.0	205.00	441.00	150.0	5.81999	291.000
353	4.9	4.40	9.06	3.3	215.60	443.94	161.7	5.75999	282.240
354	2.9	4.90	9.73	3.8	142.10	282.17	110.2	5.92999	171.970
355	3.0	3.35	8.56	3.0	100.50	256.80	90.0	5.55999	166.800
356	5.5	5.40	8.89	2.7	297.00	488.95	148.5	6.18999	340.450
357	5.5	3.35	8.71	2.7	184.25	479.05	148.5	6.01000	330.550
358	5.0	4.05	8.66	3.0	202.50	433.00	150.0	5.65999	283.000
359	4.9	4.18	9.10	3.1	204.82	445.90	151.9	6.00000	294.000
360	2.9	4.70	9.60	3.7	136.30	278.40	107.3	5.90000	171.100
361	2.6	4.30	8.59	3.3	111.80	223.34	85.8	5.29000	137.540
362	5.8	4.50	8.76	3.0	261.00	508.08	174.0	5.76000	334.080
363	5.6	3.75	8.90	2.8	210.00	498.40	156.8	6.10000	341.600
364	4.9	4.20	8.97	3.0	205.80	439.53	147.0	5.96999	292.530

Row	MY	F%	SNF%	P%	BF	SNF	P	L%	L
365	4.5	4.20	9.20	3.2	189.00	414.00	144.0	5.99999	270.000
366	2.6	5.20	9.76	3.8	135.20	253.76	98.8	5.95999	154.960
367	2.6	4.00	8.33	2.8	104.00	216.58	72.8	5.52999	143.780
368	5.5	4.90	8.60	2.5	269.50	473.00	137.5	6.09999	335.500
369	5.4	3.50	8.79	3.0	189.00	474.66	162.0	5.78999	312.660
370	4.6	4.55	9.30	3.0	209.30	427.80	138.0	6.29999	289.800
371	4.2	4.25	8.96	3.4	178.50	376.32	142.8	5.56000	233.520
372	2.3	5.10	9.66	3.8	117.30	222.18	87.4	5.85999	134.780
373	2.3	4.20	8.34	2.9	96.60	191.82	66.7	5.44000	125.120
374	5.2	4.65	8.56	2.8	241.80	445.12	145.6	5.75999	299.520
375	4.9	3.75	8.80	2.9	183.75	431.20	142.1	5.90000	289.100
376	4.7	4.20	8.79	3.0	197.40	413.13	141.0	5.79000	272.130
377	4.7	4.10	8.92	3.1	192.70	419.24	145.7	5.81999	273.540
378	2.1	4.90	9.70	4.0	102.90	203.70	84.0	5.70000	119.700
379	2.7	4.50	9.04	3.5	121.50	244.08	94.5	5.54000	149.580
380	7.2	3.80	8.79	2.6	273.60	632.88	187.2	6.18999	445.680
381	6.7	4.00	9.07	3.0	268.00	607.69	201.0	6.06999	406.690
382	5.8	4.00	8.98	3.3	232.00	520.84	191.4	5.67999	329.440
383	6.5	4.25	8.81	2.5	276.25	572.65	162.5	6.31000	410.150
384	6.8	3.70	8.70	2.4	251.60	591.60	163.2	6.30000	428.400
385	2.4	4.70	8.80	3.5	112.80	211.20	84.0	5.30000	127.200
386	6.1	4.10	8.65	2.6	250.10	527.65	158.6	6.05000	369.050
387	6.6	4.30	8.87	3.1	283.80	585.42	204.6	5.77000	380.820
388	5.0	4.50	8.96	3.5	225.00	448.00	175.0	5.45999	273.000
389	6.1	4.30	8.95	2.8	262.30	545.95	170.8	6.15000	375.150
390	6.6	3.90	8.63	4.8	257.40	569.58	316.8	3.83000	252.780
391	2.2	5.50	9.35	4.1	121.00	205.70	90.2	5.25000	115.500
392	5.8	4.60	9.03	3.1	266.80	523.74	179.8	5.92999	343.940
393	5.7	4.90	9.25	3.4	279.30	527.25	193.8	5.84999	333.450
394	4.6	5.30	9.24	3.4	243.80	425.04	156.4	5.83999	268.640
395	5.5	4.70	8.83	3.1	258.50	485.65	170.5	5.72999	315.150
396	6.2	4.25	9.08	2.7	263.50	562.96	167.4	6.38000	395.560
397	2.8	5.65	9.09	4.3	158.20	254.52	120.4	4.79000	134.120
398	6.9	4.90	8.83	3.2	338.10	609.27	220.8	5.63000	388.470
399	5.9	5.65	9.16	3.6	333.35	540.44	212.4	5.56000	328.040
400	5.9	5.70	8.92	3.6	336.30	526.28	212.4	5.32000	313.880
401	6.3	8.00	8.40	3.0	504.00	529.20	189.0	5.40000	340.200
402	6.9	4.65	8.47	2.8	320.85	584.43	193.2	5.67000	391.230
403	2.9	4.20	8.74	3.8	121.80	253.46	110.2	4.94000	143.260
404	7.0	3.50	8.86	3.0	245.00	620.20	210.0	5.85999	410.200
405	6.1	4.05	9.04	3.3	247.05	551.44	201.3	5.74000	350.140
406	6.0	3.85	8.77	3.3	231.00	526.20	198.0	5.47000	328.200
407	6.3	3.55	8.70	2.7	223.65	548.10	170.1	6.00000	378.000
408	6.9	3.75	8.47	2.8	258.75	584.43	193.2	5.67000	391.230
409	2.1	5.35	8.53	2.7	112.35	179.13	56.7	5.83000	122.430
410	5.9	3.85	8.72	3.2	227.15	514.48	188.8	5.52000	325.680
411	5.7	3.85	8.99	3.3	219.45	512.43	188.1	5.69000	324.330
412	4.8	3.95	8.86	3.4	189.60	425.28	163.2	5.46000	262.080
413	5.9	3.95	8.84	3.0	233.05	521.56	177.0	5.84000	344.560
414	6.2	3.90	8.55	3.6	241.80	530.10	223.2	4.95000	306.900
415	1.6	5.55	9.24	4.4	88.80	147.84	70.4	4.84000	77.440
416	4.9	4.55	8.95	3.4	222.95	438.55	166.6	5.54999	271.950
417	5.0	4.40	9.29	3.6	220.00	464.50	180.0	5.68999	284.500
418	4.2	4.75	9.17	3.7	199.50	385.14	155.4	5.47000	229.740
419	5.3	4.50	8.84	3.0	238.50	468.52	159.0	5.83999	309.520
420	5.3	4.15	8.73	2.8	219.95	462.69	148.4	5.93000	314.290
421	1.6	6.20	8.50	4.1	99.20	136.00	65.6	4.40000	70.400
422	5.1	4.80	8.90	3.3	244.80	453.90	168.3	5.59999	285.600
423	4.9	5.10	9.16	3.5	249.90	448.84	171.5	5.66000	277.340
424	4.4	4.90	9.25	3.9	215.60	407.00	171.6	5.35000	235.400
425	5.1	4.75	9.07	3.0	242.25	462.57	153.0	6.06999	309.570

Row	MY	F%	SNF%	P%	BF	SNF	P	L%	L
426	5.6	4.25	8.74	2.8	238.00	489.44	156.8	5.94000	332.640
427	1.9	6.40	9.40	4.0	121.60	178.60	76.0	5.39999	102.600
428	4.8	4.75	8.97	3.0	228.00	430.56	144.0	5.96999	286.560
429	5.0	5.30	9.21	3.4	265.00	460.50	170.0	5.80999	290.500
430	4.4	5.00	9.30	3.4	220.00	409.20	149.6	5.89999	259.600
431	5.2	5.00	9.08	2.8	260.00	472.16	145.6	6.27999	326.560
432	5.5	4.75	8.87	2.8	261.25	487.85	154.0	6.07000	333.850
433	1.9	5.65	9.06	3.6	107.35	172.14	68.4	5.46000	103.740
434	4.8	4.75	8.95	3.2	228.00	429.60	153.6	5.74999	276.000
435	4.8	5.05	9.18	3.3	242.40	440.64	158.4	5.87999	282.240
436	4.3	5.05	9.13	3.6	217.15	392.59	154.8	5.52999	237.790
437	5.2	4.75	8.99	2.7	247.00	467.48	140.4	6.28999	327.080
438	5.7	4.70	8.90	2.6	267.90	507.30	148.2	6.29999	359.100
439	2.4	5.85	9.04	3.9	140.40	216.96	93.6	5.13999	123.360
440	5.7	4.80	9.08	3.1	273.60	517.56	176.7	5.97999	340.860
441	4.7	5.45	9.32	3.3	256.15	438.04	155.1	6.01999	282.940
442	4.6	5.35	9.45	3.5	246.10	434.70	161.0	5.95000	273.700
443	5.6	4.80	9.10	2.8	268.80	509.60	156.8	6.30000	352.800
444	5.8	5.15	8.97	2.5	298.70	520.26	145.0	6.47000	375.260
445	2.7	5.75	8.86	3.2	155.25	239.22	86.4	5.66000	152.820
446	6.5	4.15	8.90	2.9	269.75	578.50	188.5	6.00000	390.000
447	5.6	4.60	9.10	3.1	257.60	509.60	173.6	5.99999	336.000
448	5.2	4.30	9.25	3.2	223.60	481.00	166.4	6.05000	314.600
449	6.5	3.95	8.74	2.8	256.75	568.10	182.0	5.94000	386.100
450	6.1	4.05	8.76	2.8	247.05	534.36	170.8	5.96000	363.560
451	2.2	4.70	8.93	3.4	103.40	196.46	74.8	5.53000	121.660
452	5.6	4.00	8.68	2.9	224.00	486.08	162.4	5.78000	323.680
453	5.5	4.05	9.16	3.1	222.75	503.80	170.5	6.06000	333.300
454	4.6	4.65	9.19	3.5	213.90	422.74	161.0	5.68999	261.740
455	5.5	4.20	8.96	2.6	231.00	492.80	143.0	6.35999	349.800
456	5.4	4.10	8.92	2.8	221.40	481.68	151.2	6.11999	330.479
457	1.6	5.20	9.04	3.5	83.20	144.64	56.0	5.54000	88.640
458	5.1	5.10	8.96	3.1	260.10	456.96	158.1	5.86000	298.860
459	5.1	4.60	9.08	3.1	234.60	463.08	158.1	5.97999	304.980
460	4.1	5.60	9.28	3.3	229.60	380.48	135.3	5.97999	245.180
461	5.2	5.55	9.06	3.0	288.60	471.12	156.0	6.06000	315.120
462	5.7	4.65	8.71	2.5	265.05	496.47	142.5	6.20999	353.970
463	1.9	6.10	9.40	4.0	115.90	178.60	76.0	5.39999	102.600
464	4.8	5.35	8.93	3.1	256.80	428.64	148.8	5.83000	279.840
465	4.9	5.00	9.07	3.1	245.00	444.43	151.9	5.96999	292.530
466	3.9	5.65	9.29	3.6	220.35	362.31	140.4	5.68999	221.910
467	5.0	5.05	8.90	2.7	252.50	445.00	135.0	6.19999	310.000
468	5.4	4.65	8.74	2.7	251.10	471.96	145.8	6.03999	326.160
469	1.7	6.10	9.10	3.7	103.70	154.70	62.9	5.40000	91.800
470	4.9	4.60	8.93	2.9	225.40	437.57	142.1	6.02999	295.470
471	4.8	4.85	9.14	3.1	232.80	438.72	148.8	6.03999	289.920
472	3.8	5.55	9.24	3.4	210.90	351.12	129.2	5.84000	221.920
473	4.7	6.10	8.20	2.8	286.70	385.40	131.6	5.40000	253.800
474	5.1	4.55	8.79	2.7	232.05	448.29	137.7	6.08999	310.590
475	1.5	6.20	9.09	3.8	93.00	136.35	57.0	5.29000	79.350
476	5.0	4.60	9.00	3.2	230.00	450.00	160.0	5.80000	290.000
477	4.8	5.10	9.16	3.1	244.80	439.68	148.8	6.05999	290.880
478	3.9	5.60	9.23	3.6	218.40	359.97	140.4	5.62999	219.570
479	4.5	5.75	9.09	2.9	258.75	409.05	130.5	6.18999	278.550
480	5.0	5.50	8.90	2.7	275.00	445.00	135.0	6.19999	310.000
481	1.8	7.60	9.20	3.8	136.80	165.60	68.4	5.40000	97.200
482	5.4	5.60	8.97	2.8	302.40	484.38	151.2	6.16999	333.180
483	4.5	4.70	9.13	3.0	211.50	410.85	135.0	6.13000	275.850
484	4.4	4.90	9.18	3.4	215.60	403.92	149.6	5.77999	254.320
485	4.9	5.00	8.99	2.7	245.00	440.51	132.3	6.28999	308.210
486	5.4	4.25	8.79	2.5	229.50	474.66	135.0	6.28999	339.660

Row	MY	F%	SNF%	P%	BF	SNF	P	L%	L
487	1.7	6.40	8.90	3.5	108.80	151.30	59.5	5.40000	91.800
488	5.8	3.85	8.87	3.2	223.30	514.46	185.6	5.67000	328.860
489	4.8	4.25	9.18	3.3	204.00	440.64	158.4	5.87999	282.240
490	4.8	4.40	9.00	3.0	211.20	432.00	144.0	5.99999	288.000
491	5.0	4.15	8.90	2.9	207.50	445.00	145.0	5.99999	300.000
492	5.4	4.55	8.77	2.7	245.70	473.58	145.8	6.06999	327.780
493	1.5	5.30	8.84	3.6	79.50	132.60	54.0	5.24000	78.600
494	5.1	3.65	8.87	2.9	186.15	452.37	147.9	5.96999	304.470
495	4.6	5.00	9.02	3.3	230.00	414.92	151.8	5.72000	263.120
496	4.4	4.45	9.05	3.1	195.80	398.20	136.4	5.94999	261.800
497	4.5	4.35	9.00	3.2	195.75	405.00	144.0	5.80000	261.000
498	5.3	4.40	8.71	2.9	233.20	461.63	153.7	5.80999	307.930
499	1.2	5.45	8.87	3.7	65.40	106.44	44.4	5.17000	62.040
500	4.5	4.30	8.79	3.0	193.50	395.55	135.0	5.78999	260.550
501	4.3	5.05	8.98	3.2	217.15	386.14	137.6	5.78000	248.540
502	3.8	5.30	8.96	3.3	201.40	340.48	125.4	5.65999	215.080
503	4.1	5.30	9.02	3.0	217.30	369.82	123.0	6.01999	246.820
504	4.7	4.90	8.65	2.7	230.30	406.55	126.9	5.94999	279.650

APPENDIX 9B: FULL DATA FOR MILK YIELDS, MILK CONSTITUENT YIELDS AND MILK CONSTITUENT CONTENTS (%) FOR EXPERIMENT II

The data are presented in the following format:

Cows 1 to 12 for each day of the first (non-walking) period (12 days; 144 values)

Cows 1 to 12 for each day of the second (walking) period (12 days; 144 values)

Cows 1 to 12 for each day of the third (non-walking) period (12 days; 144 values)

TOTAL 432 Values

NB. The Cow order changes.

On days 1 to 3 the order is:

1 2 3 4 5 6 7 8 9 10 11 12.

On days 4 to 15 the order is:

1 2 3 7 5 6 4 8 9 10 11 12.

On days 16 to 36 the order is:

7 2 3 1 6 5 4 8 9 11 12 10.

Seven columns of data are presented: Milk Yield (kg), Milk Fat %, Milk Protein %, Lactose %, Milk Fat Yield (g/d), Milk Protein Yield (g/d), Lactose Yield (g/d).

ROW	C	MILKY	BFAT%	PROT%	LACT%	FAT Y	PROT Y	LACT Y
1	319	9.9	4.36	3.11	4.64	432.14	308.60	459.61
2	234	9.7	3.46	3.20	4.58	336.32	311.20	444.50
3	233	10.8	3.25	3.63	4.50	351.14	392.20	487.00
4	230	11.1	2.30	3.40	4.54	255.93	377.85	504.96
5	228	6.3	2.56	3.63	4.47	161.68	229.18	282.21
6	313	9.9	3.55	3.23	4.62	351.63	319.77	458.01
7	227	10.8	3.76	3.50	4.90	406.92	378.48	529.32
8	314	10.8	2.77	3.29	4.67	299.28	356.10	504.60
9	239	5.0	4.74	4.87	4.48	237.02	243.98	224.06
10	836	9.6	2.89	3.29	4.75	277.59	316.35	456.66
11	321	9.2	3.48	3.27	4.74	320.60	301.12	436.08
12	311	10.7	3.62	3.63	4.83	387.51	388.41	517.74
13	319	10.1	4.22	3.39	4.69	426.90	342.51	474.48
14	234	9.9	3.73	3.23	4.69	370.15	320.43	465.19
15	233	11.5	3.32	3.55	4.56	381.96	409.01	525.04
16	230	11.2	2.83	3.39	4.57	317.03	380.66	512.68
17	228	6.2	2.71	3.67	4.45	168.26	227.82	276.22
18	313	9.9	3.37	3.37	4.64	334.08	334.08	460.08
19	227	10.9	3.14	3.57	4.86	342.73	389.81	530.19
20	314	11.0	3.14	3.19	4.68	345.70	351.73	515.23
21	239	4.4	3.63	5.07	4.49	160.10	223.19	197.85
22	836	9.4	2.86	3.25	5.04	269.65	306.05	473.81
23	321	10.1	3.32	3.16	4.68	336.09	319.39	473.47
24	311	10.9	3.39	3.60	4.79	369.71	393.33	522.98
25	319	9.8	3.94	3.32	4.80	386.34	325.68	470.61
26	234	9.9	3.41	3.05	4.61	338.14	302.28	457.27
27	233	10.4	3.28	3.58	4.42	341.38	372.54	460.46
28	230	10.1	2.90	3.21	4.54	292.98	325.19	459.00
29	228	5.0	2.42	3.89	4.54	121.30	194.80	227.11
30	313	9.3	3.76	3.35	4.69	349.76	312.47	436.46
31	227	9.9	3.06	3.60	4.83	303.18	356.98	478.48
32	314	11.0	3.02	3.39	4.74	332.80	373.00	522.10
33	239	3.8	4.35	5.14	4.47	165.62	195.50	169.98
34	836	8.2	2.61	3.37	5.24	214.23	276.50	429.84
35	321	10.3	3.17	3.39	4.69	327.06	349.90	483.94
36	311	10.9	3.32	3.62	4.78	362.20	395.18	521.02
37	319	10.1	4.10	3.44	4.71	415.06	347.90	475.81
38	234	10.2	3.43	3.15	4.67	350.53	322.09	476.65
39	233	9.8	3.86	3.81	4.50	379.10	373.83	441.19
40	227	9.5	3.97	3.57	4.85	377.98	339.59	461.17
41	228	4.2	2.22	4.03	4.53	93.56	169.32	190.64
42	313	9.9	3.96	3.43	4.71	392.31	340.29	466.74
43	230	10.3	2.69	3.46	4.86	277.50	356.82	501.41
44	314	11.9	3.08	3.29	4.69	366.63	391.63	558.65
45	239	3.8	6.15	5.45	4.28	233.85	207.34	162.72
46	836	9.6	2.60	3.51	5.02	250.52	337.36	482.85
47	321	10.6	3.14	3.42	4.61	333.44	363.36	489.62
48	311	12.0	3.46	3.61	4.67	415.92	434.32	561.12
49	319	9.9	3.97	3.46	4.80	393.80	342.98	475.31
50	234	9.7	3.47	3.26	4.73	336.97	316.57	459.07
51	233	9.6	3.50	3.90	4.58	336.92	374.94	439.72
52	227	9.2	4.37	3.60	4.86	402.56	331.28	447.92
53	228	4.7	2.95	4.05	4.36	138.86	190.52	205.29
54	313	9.6	3.70	3.50	4.74	355.92	336.24	455.22
55	230	10.7	2.83	3.46	4.97	303.53	371.12	532.85
56	314	11.6	3.02	3.27	4.73	351.41	380.39	549.05
57	239	3.1	4.26	5.34	4.54	132.15	165.77	140.75
58	836	9.6	2.52	3.62	4.81	242.52	347.64	462.00
59	321	10.5	3.22	3.45	4.70	338.86	363.08	493.75
60	311	10.5	3.49	3.68	4.87	366.50	386.72	511.55

Row	cow	MY	F%	P%	L%	F	P	L
61	319	9.9	4.04	3.58	4.87	400.73	355.08	482.57
62	234	10.0	3.63	3.36	4.77	363.30	336.75	477.65
63	233	10.3	3.63	3.84	4.80	374.38	395.78	494.66
64	227	8.4	4.20	3.66	4.97	353.52	307.56	417.96
65	228	3.9	2.90	4.12	4.29	113.31	160.86	167.46
66	313	10.0	3.84	3.60	4.76	384.60	360.64	476.32
67	230	11.0	2.07	3.33	4.69	228.40	366.66	516.36
68	314	12.2	3.05	3.29	4.74	373.12	401.62	578.71
69	239	3.1	5.84	5.53	4.28	181.28	171.71	132.86
70	836	9.9	2.83	3.69	5.06	280.39	366.19	501.82
71	321	10.4	3.36	3.30	4.76	350.29	343.63	495.43
72	311	11.3	3.23	3.62	4.89	365.80	409.08	553.05
73	319	10.4	3.99	3.59	4.88	415.69	373.43	507.69
74	234	10.2	3.56	3.33	4.78	363.99	339.74	488.09
75	233	11.0	3.15	3.78	4.56	346.76	416.50	501.78
76	227	8.0	4.14	3.65	5.03	331.65	292.40	402.90
77	228	3.1	2.46	4.10	4.15	76.30	127.16	128.73
78	313	10.5	3.72	3.52	4.74	390.90	369.81	498.33
79	230	9.5	2.43	3.46	4.70	230.95	329.40	446.95
80	314	12.2	3.01	3.31	4.74	367.81	404.49	579.14
81	239	3.0	5.34	5.35	4.44	160.35	160.50	133.20
82	836	9.8	2.74	3.73	5.17	269.08	365.55	507.33
83	321	10.2	3.37	3.45	4.80	344.46	352.72	489.86
84	311	10.9	3.53	3.67	4.94	385.37	400.42	539.44
85	319	10.1	4.03	3.55	4.86	407.72	358.78	491.42
86	234	10.2	3.79	3.41	4.83	386.92	347.98	493.28
87	233	10.2	3.78	3.91	4.65	385.98	398.92	475.16
88	227	9.0	4.47	3.67	4.98	403.06	331.06	448.22
89	228	1.9	2.43	4.41	3.59	46.27	83.93	68.39
90	313	10.1	4.16	3.45	4.73	420.66	348.92	478.04
91	230	8.8	3.39	3.49	4.71	298.70	307.69	415.17
92	314	11.5	3.28	3.50	4.76	377.53	402.72	547.40
93	239	3.1	5.44	5.37	4.45	168.88	166.50	138.07
94	836	9.7	2.44	3.69	5.05	236.72	358.61	490.53
95	321	9.8	3.69	3.44	4.85	362.04	337.55	476.09
96	311	10.4	3.35	3.52	4.99	349.18	366.19	519.41
97	319	10.2	4.07	3.46	4.69	415.74	352.92	478.38
98	234	10.0	3.59	3.40	4.66	359.50	340.50	466.50
99	233	10.1	4.25	3.89	4.56	429.48	392.89	460.84
100	227	8.2	4.89	3.60	4.81	401.74	295.38	394.62
101	228	2.8	3.88	4.38	3.58	108.87	122.81	100.34
102	313	9.9	4.10	3.40	4.70	406.74	337.19	465.32
103	230	9.7	3.69	3.60	4.60	358.18	349.43	446.95
104	314	12.0	3.11	3.30	4.66	373.31	396.63	559.81
105	239	3.4	5.85	5.29	4.32	199.18	180.02	146.98
106	836	10.6	3.08	3.59	4.90	327.38	380.81	520.26
107	321	10.1	3.62	3.40	4.64	366.43	343.52	469.59
108	311	10.4	3.37	3.56	4.92	351.14	371.24	512.22
109	319	10.0	4.12	3.51	4.75	412.60	351.95	475.70
110	234	10.2	3.92	3.34	4.68	399.96	341.47	477.44
111	233	10.2	3.93	3.92	4.53	401.22	400.50	462.68
112	227	7.8	4.08	3.80	4.88	319.01	296.80	380.99
113	228	2.7	3.11	4.02	3.93	84.07	108.79	106.22
114	313	9.7	4.33	3.47	4.78	420.37	336.73	463.83
115	230	8.7	2.30	3.46	4.66	200.41	301.49	406.27
116	314	12.2	2.93	3.37	4.70	358.44	411.24	574.42
117	239	2.9	4.43	5.23	4.36	128.53	151.71	126.60
118	836	9.3	3.10	3.77	4.94	289.02	351.21	459.43
119	321	9.8	3.79	3.41	4.70	371.56	335.02	460.74
120	311	10.5	3.11	3.85	4.80	326.86	405.08	504.36
121	319	9.2	4.32	3.59	4.80	397.58	331.19	441.70

Row	Cow	MY	F%	P%	L%	F	P	L
122	234	9.4	3.65	3.38	4.71	343.50	317.72	443.36
123	233	10.1	4.20	4.00	4.51	424.87	404.48	455.56
124	227	7.4	4.39	3.89	4.88	325.08	288.37	361.36
125	228	2.6	3.53	3.99	3.80	92.02	103.88	98.83
126	313	8.8	4.51	3.75	4.75	397.17	330.30	418.65
127	230	8.8	1.97	3.62	4.65	173.90	319.09	409.43
128	314	11.9	2.96	3.44	4.72	352.70	409.62	561.69
129	239	2.7	5.58	5.36	4.19	150.86	144.76	113.27
130	836	8.3	2.12	3.56	4.94	176.00	296.21	410.54
131	321	9.4	3.76	3.44	4.68	354.20	323.72	440.26
132	311	10.5	3.24	3.91	4.75	341.21	411.14	499.74
133	319	9.1	4.24	3.59	4.79	386.19	326.69	436.59
134	234	9.2	3.83	3.41	4.76	352.66	314.02	438.13
135	233	9.7	4.10	4.00	4.55	398.49	388.61	441.97
136	227	7.0	4.80	3.91	4.86	336.64	274.33	340.27
137	228	2.2	3.63	4.05	3.87	79.97	89.21	85.14
138	313	8.7	4.12	3.77	4.75	358.63	328.29	413.81
139	230	7.6	1.54	3.98	4.74	117.12	302.60	360.24
140	314	11.5	3.18	3.42	4.75	366.18	394.19	546.88
141	239	3.0	6.26	5.19	4.29	187.91	155.86	128.75
142	836	8.1	2.41	3.67	4.94	195.50	297.62	400.73
143	321	8.9	3.84	3.52	4.67	342.46	313.67	416.19
144	311	10.6	3.74	3.85	4.80	396.98	408.62	509.34
145	319	8.9	4.56	3.38	4.76	405.93	301.45	424.44
146	234	9.2	4.30	3.26	4.72	395.94	300.76	434.38
147	233	9.3	4.42	3.87	4.55	411.87	360.69	423.15
148	227	6.7	5.09	3.75	4.83	341.65	251.84	323.66
149	228	1.7	3.30	3.84	3.80	56.15	65.43	64.71
150	313	8.7	4.53	3.60	4.71	394.47	313.83	410.31
151	230	7.4	1.74	3.90	4.79	129.06	289.30	354.48
152	314	11.1	3.24	3.36	4.75	360.01	373.82	527.65
153	239	2.7	4.78	4.96	4.36	129.30	133.96	117.76
154	836	5.9	1.82	3.92	5.22	107.38	231.30	308.24
155	321	8.3	3.72	3.35	4.75	309.11	278.09	394.88
156	311	10.4	3.65	3.79	4.79	379.76	395.17	498.63
157	319	7.8	5.20	3.75	4.50	405.74	292.92	351.22
158	234	7.8	4.43	3.45	4.62	345.60	269.14	361.12
159	233	7.7	5.56	4.41	4.43	428.34	339.60	341.76
160	227	4.3	7.02	4.08	4.61	302.25	175.72	198.49
161	228	1.6	3.92	3.87	3.82	62.72	62.00	61.20
162	313	7.1	6.21	3.91	4.51	441.60	278.17	320.67
163	230	7.0	2.04	4.25	4.58	143.40	297.60	321.20
164	314	9.2	4.07	3.43	4.70	374.46	316.12	432.96
165	239	1.7	5.69	5.50	4.05	96.83	93.59	68.99
166	836	5.0	2.20	4.11	5.04	110.38	205.52	252.26
167	321	7.5	4.18	3.31	4.69	313.53	248.91	351.87
168	311	8.3	4.20	3.99	4.71	349.02	331.22	391.31
169	319	8.8	4.89	3.47	4.67	430.44	305.69	411.26
170	234	8.2	4.87	3.31	4.64	399.74	271.58	381.08
171	233	7.3	4.98	4.34	4.49	363.75	317.45	328.36
172	227	4.1	7.34	3.92	4.58	300.95	160.92	187.86
173	228	2.0	3.87	3.72	3.81	77.53	74.56	76.26
174	313	7.3	5.38	3.87	4.48	393.20	282.69	327.72
175	230	7.3	2.13	3.99	4.66	156.14	291.40	340.86
176	314	8.7	3.88	3.26	4.69	337.67	283.67	408.35
177	239	2.8	5.06	4.91	4.18	141.92	137.72	117.24
178	836	6.3	4.07	3.66	4.70	256.65	230.61	296.70
179	321	7.9	4.12	3.34	4.63	325.64	264.50	366.41
180	311	8.6	4.19	3.75	4.73	360.44	322.64	406.90
181	227	6.2	3.93	3.53	4.77	244.11	219.37	296.20
182	234	9.3	3.91	3.19	4.80	364.17	296.94	447.18

Row	cow	MY	F%	P%	L%	F	P	L
183	233	8.8	4.49	3.90	4.75	395.62	343.86	418.08
184	319	9.6	4.60	3.64	5.07	442.38	350.34	487.08
185	313	9.3	2.56	3.55	3.86	238.13	330.42	359.30
186	228	2.2	4.31	3.42	4.81	95.02	75.42	105.82
187	230	8.4	1.57	3.94	4.80	132.04	331.74	403.52
188	314	10.7	2.91	3.18	4.80	311.46	340.83	514.17
189	239	3.4	4.25	4.59	4.36	144.67	156.06	148.41
190	321	9.7	4.03	3.87	5.02	391.80	375.54	487.33
191	311	10.1	3.90	3.38	4.61	394.04	341.71	466.48
192	836	6.7	3.59	3.47	4.86	240.70	233.01	325.93
193	227	6.1	4.37	3.65	4.89	266.86	222.80	298.66
194	234	8.9	3.73	3.21	4.71	332.21	286.12	419.54
195	233	8.1	3.96	3.98	4.68	321.05	322.75	379.61
196	319	9.0	3.75	3.63	4.74	337.85	327.34	426.84
197	313	8.3	3.91	3.46	4.61	325.06	287.20	382.80
198	228	1.9	2.52	3.61	3.95	47.98	68.66	75.05
199	230	9.2	1.80	3.99	4.67	165.94	367.95	430.25
200	314	10.4	2.93	3.32	4.74	305.24	345.31	493.27
201	239	3.0	4.64	4.92	4.23	139.34	147.62	127.13
202	321	9.5	3.92	3.34	4.64	373.09	317.56	440.95
203	311	9.4	3.07	3.75	4.85	289.48	352.52	456.30
204	836	5.6	0.67	1.53	2.00	37.72	85.79	112.01
205	227	4.8	7.12	3.83	4.67	341.76	184.08	224.48
206	234	8.4	4.71	3.32	4.72	396.20	279.24	396.56
207	233	6.7	5.64	4.70	4.44	378.43	315.28	297.71
208	319	7.8	5.12	3.91	4.62	399.96	305.04	361.02
209	313	6.9	5.73	3.87	4.53	395.67	267.60	313.11
210	228	2.0	4.11	3.59	3.71	82.28	71.88	74.32
211	230	7.5	2.34	4.11	4.62	175.63	308.35	346.95
212	314	10.0	3.28	3.45	4.70	328.60	345.64	470.32
213	239	2.0	6.65	5.90	3.83	133.00	118.10	76.60
214	321	8.7	4.75	3.45	4.64	413.39	300.96	404.50
215	311	8.7	3.95	4.09	4.71	343.67	355.94	409.92
216	836	7.1	2.48	3.75	4.82	176.39	266.71	342.79
217	227	6.2	5.52	3.52	4.80	342.76	218.50	298.13
218	234	8.5	4.30	3.30	4.74	365.69	280.99	403.57
219	233	7.0	4.19	4.36	4.53	293.72	305.51	317.66
220	319	8.2	4.25	3.61	4.78	349.26	296.56	392.16
221	313	6.6	5.14	3.77	4.73	339.54	249.24	312.66
222	228	1.9	3.35	3.65	4.05	63.71	69.38	77.13
223	230	7.8	2.78	3.86	4.78	217.14	301.78	373.44
224	314	9.5	3.14	3.45	4.78	299.02	328.16	454.51
225	239	2.2	4.97	5.37	4.27	109.42	118.14	94.14
226	321	7.7	3.97	3.55	4.74	306.24	273.60	365.02
227	311	7.1	3.45	3.82	4.88	245.17	271.25	346.48
228	836	7.1	2.77	3.74	5.02	196.97	265.59	357.00
229	227	6.2	4.61	3.62	4.96	286.06	224.98	307.80
230	234	9.4	3.96	3.23	4.77	372.84	303.62	448.81
231	233	8.4	4.14	4.04	4.64	348.48	339.45	389.82
232	319	8.7	3.74	3.57	4.91	325.38	311.04	427.38
233	313	8.5	4.38	3.49	4.91	373.04	296.93	417.63
234	228	1.9	2.79	3.71	3.86	53.05	70.49	73.40
235	230	9.6	2.47	3.65	4.85	237.66	350.40	466.02
236	314	10.8	3.29	3.40	4.79	356.37	367.20	518.01
237	239	3.0	5.91	4.71	4.28	177.50	141.46	128.56
238	321	8.9	4.16	3.41	4.66	370.28	304.18	414.94
239	311	9.5	3.37	3.64	4.93	320.81	345.80	468.53
240	836	9.2	2.97	3.60	4.95	273.72	331.32	456.20
241	227	5.7	4.14	3.52	4.90	236.52	200.84	279.57
242	234	8.6	3.42	3.20	4.81	294.16	275.80	413.66
243	233	7.7	3.82	3.87	4.60	294.49	298.29	354.61

Row	cow	MY	F%	P%	L%	F	P	L
244	319	7.8	3.79	3.49	4.88	296.10	272.28	381.12
245	313	7.7	4.06	3.43	4.82	313.32	264.67	371.42
246	228	1.7	2.97	3.67	3.96	50.57	62.45	67.38
247	230	9.0	2.80	3.54	4.70	252.30	318.96	423.66
248	314	10.0	3.27	3.33	4.78	327.84	333.24	478.60
249	239	2.5	3.41	4.67	4.41	85.26	116.94	110.41
250	321	8.8	3.86	3.35	4.75	339.73	295.00	418.59
251	311	9.3	3.45	3.58	4.91	321.01	333.04	457.32
252	836	7.0	2.46	3.66	4.96	172.33	256.36	347.21
253	227	4.5	5.42	3.83	4.89	244.05	172.45	220.05
254	234	8.8	4.19	3.18	4.85	369.17	280.64	427.20
255	233	7.0	5.24	4.28	4.56	367.15	300.12	319.62
256	319	7.7	4.58	3.59	4.82	353.10	276.98	371.80
257	313	7.9	4.45	3.46	4.73	352.28	273.85	373.91
258	228	1.6	4.34	3.60	4.08	69.48	57.67	65.35
259	230	8.4	2.88	3.54	4.66	242.16	297.81	391.80
260	314	9.6	3.89	3.37	4.76	373.84	323.68	457.68
261	239	2.3	4.13	4.80	4.18	95.00	110.50	96.25
262	321	7.9	4.46	3.35	4.79	352.76	264.99	378.74
263	311	9.4	3.64	3.76	4.83	342.82	353.98	454.30
264	836	7.4	2.62	3.50	4.93	194.04	259.42	364.84
265	227	4.4	5.49	3.67	4.92	241.56	161.70	216.70
266	234	8.3	3.97	3.17	4.86	329.65	263.22	403.59
267	233	6.7	4.64	4.11	4.60	310.93	275.81	308.55
268	319	7.4	3.88	3.50	4.92	287.43	259.72	364.15
269	313	7.7	4.20	3.35	4.71	323.80	258.22	362.78
270	228	1.7	3.59	3.48	4.22	61.03	59.18	71.88
271	230	6.6	2.09	3.90	4.76	138.38	257.67	314.31
272	314	9.6	3.52	3.34	4.82	338.54	320.77	463.05
273	239	2.0	3.89	4.72	4.25	77.80	94.50	85.00
274	321	7.8	4.32	3.27	4.74	337.44	255.54	370.30
275	311	9.4	3.56	3.76	4.85	334.78	353.68	456.58
276	836	5.8	2.28	3.41	5.07	132.30	197.83	294.22
277	227	5.3	5.24	3.54	4.95	278.16	187.97	262.64
278	234	8.4	4.17	3.19	4.87	350.28	268.08	409.86
279	233	7.6	4.52	3.77	4.67	343.88	286.52	355.18
280	319	7.7	3.88	3.55	4.97	299.32	273.42	382.97
281	313	8.3	4.44	3.35	4.78	369.18	278.74	396.89
282	228	1.9	3.32	3.53	4.35	63.22	67.20	82.78
283	230	6.6	2.55	4.11	4.85	168.60	271.61	320.45
284	314	9.8	3.31	3.39	4.87	325.06	332.98	477.50
285	239	2.6	5.81	4.50	4.17	151.26	117.12	108.58
286	321	7.7	3.78	3.30	4.78	291.37	254.56	368.34
287	311	9.4	3.28	3.68	4.92	308.54	345.98	463.18
288	836	5.7	2.84	3.75	5.09	162.10	214.01	290.55
289	227	5.6	4.22	3.48	5.00	236.77	195.42	280.06
290	234	9.3	3.87	3.08	4.79	360.49	286.74	445.72
291	233	8.1	3.94	3.64	4.67	319.62	295.50	378.33
292	319	7.7	3.48	3.47	4.91	268.31	267.68	378.63
293	313	8.1	3.40	3.24	4.70	275.40	262.44	380.97
294	228	2.0	2.49	3.45	4.33	49.90	69.10	86.60
295	230	6.9	1.65	3.92	4.89	114.21	270.57	338.04
296	314	10.3	3.33	3.26	4.77	343.19	336.25	492.16
297	239	2.5	4.10	4.36	4.31	102.74	109.10	107.98
298	321	8.5	3.34	3.22	4.68	284.06	274.08	398.58
299	311	10.0	3.21	3.58	4.88	321.08	358.62	488.00
300	836	6.0	2.27	3.68	5.12	136.72	220.96	307.20
301	227	5.7	5.03	3.72	4.94	287.22	212.40	281.73
302	234	9.4	4.06	3.12	4.76	381.76	293.82	448.24
303	233	8.4	4.02	3.70	4.66	338.16	311.16	392.04
304	319	7.4	3.72	3.48	4.91	275.66	257.84	363.80

Row	cow	MY	F%	P%	L%	F	P	L
305	313	8.6	4.16	3.22	4.67	358.20	276.92	401.76
306	228	2.0	3.57	3.39	4.23	71.56	67.92	84.64
307	230	7.6	1.57	3.91	4.88	119.70	297.60	371.58
308	314	10.7	3.07	3.25	4.81	328.83	347.99	515.42
309	239	2.0	4.74	4.76	4.15	94.80	95.26	83.15
310	321	8.2	3.51	3.22	4.67	288.42	264.42	383.28
311	311	10.3	3.14	3.64	4.85	323.90	375.61	499.55
312	836	6.8	2.30	3.62	5.04	156.75	246.26	342.91
313	227	5.5	4.50	3.74	4.96	247.65	206.00	272.95
314	234	8.6	3.77	3.17	4.87	324.90	272.98	419.48
315	233	7.4	3.81	3.87	4.77	281.98	286.40	353.40
316	319	6.9	3.98	3.49	4.93	274.68	241.02	340.26
317	313	7.9	4.16	3.32	4.73	329.14	262.95	373.72
318	228	1.8	2.79	3.59	4.30	50.34	64.74	77.52
319	230	7.6	1.56	3.97	4.92	118.96	301.88	374.32
320	314	10.2	3.04	3.24	4.88	310.83	331.35	497.92
321	239	1.9	3.60	4.75	4.38	68.43	90.33	83.37
322	321	8.0	3.87	3.28	4.72	309.80	262.80	378.25
323	311	9.8	3.19	3.67	4.83	312.66	359.90	474.03
324	836	6.9	2.54	3.67	5.01	175.41	253.75	346.26
325	227	5.7	4.54	3.78	4.90	258.83	215.95	279.83
326	234	9.1	4.52	3.14	4.76	411.91	286.42	433.25
327	233	7.5	4.24	3.99	4.61	318.47	299.66	345.85
328	319	7.0	3.97	3.52	4.93	278.10	246.90	345.20
329	313	7.6	4.36	3.45	4.81	331.54	262.63	366.09
330	228	1.7	3.43	3.70	4.24	58.31	63.01	72.16
331	230	7.8	1.89	3.85	4.81	147.72	300.30	375.30
332	314	10.5	3.11	3.30	4.82	327.50	346.50	506.89
333	239	1.6	6.28	5.12	4.11	100.50	82.00	65.82
334	321	7.6	3.64	3.26	4.84	277.20	248.02	368.24
335	311	10.2	3.33	3.66	4.84	340.49	373.37	493.68
336	836	7.5	2.11	3.64	4.87	158.73	273.18	365.91
337	227	5.5	4.75	3.71	4.83	261.56	204.34	266.17
338	234	8.5	3.54	3.13	4.68	301.35	266.27	398.06
339	233	6.9	3.98	4.02	4.64	274.92	277.38	320.60
340	319	6.4	4.02	3.49	4.84	257.48	223.56	310.04
341	313	7.1	4.34	3.42	4.73	308.51	243.05	335.97
342	228	1.3	2.58	3.81	4.32	33.63	49.60	56.24
343	230	7.5	1.94	3.79	4.81	145.95	284.93	361.15
344	314	10.3	3.08	3.27	4.75	317.95	337.55	489.34
345	239	1.6	4.30	5.38	3.99	68.84	86.16	63.92
346	321	7.5	4.30	3.26	4.79	322.67	244.70	359.78
347	311	9.6	3.39	3.61	4.82	326.23	347.49	462.82
348	836	5.8	2.37	3.84	4.88	137.53	222.98	283.37
349	227	5.7	4.88	3.66	4.78	278.52	208.95	272.55
350	234	8.7	4.11	3.17	4.72	357.96	276.54	410.73
351	233	7.3	4.06	3.99	4.65	296.68	291.62	339.78
352	319	6.8	4.01	3.46	4.83	273.28	235.44	328.68
353	313	7.3	4.35	3.38	4.66	318.06	247.04	340.18
354	228	1.2	2.13	3.84	4.20	25.64	46.12	50.43
355	230	7.7	1.49	3.97	4.87	114.84	306.04	375.38
356	314	10.1	3.17	3.31	4.75	320.48	334.48	480.34
357	239	1.4	5.42	5.58	3.87	76.00	78.12	54.24
358	321	8.1	3.62	3.43	4.58	293.50	277.98	371.77
359	311	10.0	3.63	3.69	4.75	363.66	369.94	475.24
360	836	6.3	2.11	3.74	5.06	133.07	236.18	319.20
361	227	5.5	4.37	3.65	4.82	240.85	201.05	265.15
362	234	8.8	3.79	3.19	4.71	334.32	281.12	414.96
363	233	7.1	3.96	4.12	4.66	281.20	292.81	331.11
364	319	6.4	4.04	3.46	4.79	258.64	221.95	306.63
365	313	7.2	3.98	3.43	4.70	286.86	247.38	339.00

Row	Cow	MY	F%	P%	L%	F	P	L
366	228	1.3	3.39	3.95	4.20	44.18	51.37	54.65
367	230	7.4	1.78	3.99	4.75	132.06	295.82	351.54
368	314	10.1	3.25	3.31	4.71	328.28	334.48	475.79
369	239	1.0	4.44	5.89	3.92	44.40	58.95	39.20
370	321	7.3	3.70	3.48	4.67	270.67	254.66	341.18
371	311	9.5	3.67	3.63	4.79	348.79	345.68	455.66
372	836	6.8	2.28	3.71	5.05	155.08	252.68	343.76
373	227	4.7	4.83	3.76	4.83	227.30	176.95	227.01
374	234	8.5	4.03	3.25	4.76	343.20	276.65	405.00
375	233	6.4	4.52	4.29	4.66	289.72	274.68	298.64
376	319	5.8	4.43	3.70	4.91	257.16	215.17	285.11
377	313	6.8	4.44	3.57	4.78	302.38	243.30	325.42
378	228	0.8	2.24	4.20	4.16	17.92	33.60	33.28
379	230	6.5	1.54	4.32	4.81	100.29	281.02	312.93
380	314	9.9	3.34	3.36	4.74	330.87	332.94	470.10
381	239	0.9	5.74	6.07	3.93	51.71	54.68	35.41
382	321	6.8	3.85	3.47	4.81	262.33	236.49	327.46
383	311	9.4	3.57	3.75	4.84	335.60	352.64	454.96
384	836	6.0	1.64	3.93	4.97	98.52	236.28	298.20
385	227	5.2	4.71	3.67	4.78	244.97	191.15	248.62
386	234	8.1	4.00	3.25	4.76	324.64	263.77	385.90
387	233	5.8	4.53	4.32	4.67	263.03	250.80	271.19
388	319	5.5	4.55	3.70	4.85	250.65	203.73	266.89
389	313	6.3	4.04	3.59	4.75	254.61	226.71	299.34
390	228	0.9	2.80	4.45	3.97	25.24	40.07	35.81
391	230	6.0	1.74	4.36	4.79	104.92	261.92	287.92
392	314	9.3	3.32	3.39	4.81	308.97	315.82	447.44
393	239	0.6	5.89	6.29	3.89	35.36	37.78	23.34
394	321	6.3	3.35	3.48	4.85	211.26	219.82	305.89
395	311	9.1	3.36	3.74	4.83	306.03	341.14	440.22
396	836	6.0	4.57	3.98	4.81	274.58	238.98	288.62
397	227	4.8	4.92	3.76	4.79	236.28	180.69	230.34
398	234	8.0	4.11	3.25	4.76	329.29	260.19	380.85
399	233	6.3	4.14	4.25	4.75	261.33	267.86	299.25
400	319	5.1	4.80	3.55	4.88	244.83	181.14	249.32
401	313	6.3	4.36	3.54	4.75	275.13	223.47	299.70
402	228	0.8	3.45	4.53	3.96	27.64	36.24	31.68
403	230	6.3	2.41	4.22	4.80	152.21	265.86	302.88
404	314	8.8	3.53	3.41	4.75	310.74	300.26	418.36
405	239	0.5	5.25	6.47	3.67	26.26	32.39	18.35
406	321	5.8	3.63	3.63	4.71	211.03	211.11	273.25
407	311	8.7	3.83	3.80	4.89	333.49	331.31	426.19
408	836	6.1	2.80	3.67	5.00	171.14	223.99	305.32
409	227	4.6	4.47	3.83	4.87	205.85	176.41	224.25
410	234	8.0	3.40	3.38	4.78	272.04	271.08	382.92
411	233	6.2	4.12	4.36	4.74	255.85	270.73	294.34
412	319	5.6	4.18	3.63	4.90	234.56	203.44	274.72
413	313	6.5	4.52	3.69	4.73	294.00	240.40	307.50
414	228	0.7	2.74	4.58	3.91	19.20	32.11	27.43
415	230	5.6	1.84	4.22	4.79	103.08	236.58	268.68
416	314	9.3	3.17	3.38	4.69	295.11	315.03	436.74
417	239	0.3	3.84	6.72	2.92	11.53	20.16	8.77
418	321	6.6	3.52	3.68	4.60	232.92	243.08	304.15
419	311	8.9	3.70	3.79	4.82	329.87	337.53	429.26
420	836	6.6	3.09	3.76	4.95	203.94	248.70	327.30
421	227	4.5	5.11	3.99	4.80	230.00	179.75	216.03
422	234	7.6	4.57	3.38	4.73	347.72	257.46	359.80
423	233	6.0	4.81	4.56	4.73	289.12	273.76	284.00
424	319	5.0	4.47	3.86	4.87	223.92	193.36	243.88
425	313	5.7	4.93	4.05	4.76	281.16	231.00	271.47
426	228	0.6	2.70	4.83	3.68	16.20	29.01	22.11

Row	cow	MY	F%	P%	L%	F	P	L
427	230	5.6	2.71	4.26	4.71	151.94	238.76	263.98
428	314	9.3	3.46	3.43	4.79	322.07	319.00	446.14
429	239	0.2	6.37	7.51	3.22	12.75	15.03	6.45
430	321	5.9	4.61	3.77	4.76	272.47	222.53	281.16
431	311	8.8	3.79	3.80	4.85	333.98	334.52	427.18
432	836	6.8	3.13	3.71	4.94	213.50	252.40	336.35

APPENDIX 9C: FULL DATA FOR MILK YIELDS, MILK CONSTITUENT YIELDS AND MILK CONSTITUENT CONTENTS (%) FOR EXPERIMENT III

The data are presented in the following format:

Cows 1 to 12 for three days (36 values) for co-variates

Cows 1 to 12 for each day of the first (non-walking) period (12 days; 144 values)

Cows 1 to 12 for each day of the second (walking) period (12 days; 144 values)

Cows 1 to 12 for each day of the third (non-walking) period (12 days; 144 values)

TOTAL 468 Values.

Seven columns of data are presented: Milk Yield (kg), Milk Fat %, Milk Protein %, Lactose %, Milk Fat Yield (g/d), Milk Protein Yield (g/d), Lactose Yield (g/d).

ROW	MILKY	FAT%	PROT%	LACT%	FAT	PROTEIN	LACTOSE	PERIODS
1	6.5	3.80	3.13	4.85	247.00	203.45	315.250	1
2	5.1	4.35	3.23	4.60	221.85	164.73	234.600	1
3	4.3	4.33	3.53	4.76	186.19	151.79	204.680	1
4	4.7	4.06	3.32	4.77	190.82	156.04	224.190	1
5	4.7	3.96	3.38	3.47	186.12	158.86	163.090	1
6	7.3	3.92	3.20	4.61	286.16	233.60	336.530	1
7	5.3	3.97	2.98	5.01	210.41	157.94	265.530	1
8	5.0	3.76	3.37	5.23	188.00	168.50	261.500	1
9	5.7	3.96	2.98	4.65	225.72	169.86	265.050	1
10	4.5	3.57	3.02	4.47	160.65	135.90	201.150	1
11	6.8	3.14	2.80	4.58	213.52	190.40	311.440	1
12	5.2	3.96	3.13	4.91	205.92	162.76	255.320	1
13	6.7	4.05	3.12	4.83	271.35	209.04	323.610	1
14	4.7	4.19	3.20	4.68	196.93	150.40	219.960	1
15	6.6	4.38	3.57	4.73	289.08	235.62	312.180	1
16	5.1	4.10	3.36	4.89	209.10	171.36	249.390	1
17	5.3	3.02	3.00	4.14	160.06	159.00	219.420	1
18	7.7	3.88	3.17	4.68	298.76	244.09	360.360	1
19	5.8	3.82	2.97	5.09	221.56	172.26	295.220	1
20	5.3	3.91	3.40	5.13	207.23	180.20	271.890	1
21	5.9	3.86	2.97	4.72	227.74	175.23	278.480	1
22	4.6	3.94	3.13	4.45	181.24	143.98	204.700	1
23	7.5	3.14	2.80	4.58	235.50	210.00	343.500	1
24	5.0	3.42	3.15	5.09	171.00	157.50	254.500	1
25	6.9	3.67	3.08	4.69	253.23	212.52	323.610	1
26	4.7	4.39	3.24	4.64	206.33	152.28	218.080	1
27	6.9	4.23	3.16	4.91	291.87	218.04	338.790	1
28	5.2	4.24	3.20	4.64	220.48	166.40	241.280	1
29	4.6	3.38	3.28	4.41	155.48	150.88	202.860	1
30	7.7	4.00	3.10	4.73	308.00	238.70	364.210	1
31	5.6	3.47	3.14	4.80	194.32	175.84	268.800	1
32	5.1	4.00	3.34	4.88	204.00	170.34	248.880	1
33	5.3	3.99	3.27	4.88	211.47	173.31	258.640	1
34	4.4	3.47	3.12	4.26	152.68	137.28	187.440	1
35	6.8	3.22	2.79	4.55	218.96	189.72	309.400	1
36	5.5	3.87	3.03	5.00	212.85	166.65	275.000	1
37	6.8	4.01	3.00	4.63	272.68	204.00	314.840	2
38	5.5	4.19	3.21	4.55	230.45	176.55	250.250	2
39	5.4	4.58	3.45	4.71	247.32	186.30	254.340	2
40	5.0	4.15	3.28	4.74	207.50	164.00	237.000	2
41	4.4	3.00	2.98	4.16	132.00	131.12	183.040	2
42	7.5	3.65	3.17	4.62	273.75	237.75	346.500	2
43	5.1	3.84	3.08	4.91	195.84	157.08	250.410	2
44	5.4	4.01	3.47	4.96	216.54	187.38	267.840	2
45	5.9	3.66	3.09	4.65	215.94	182.31	274.350	2
46	4.4	3.46	3.35	4.50	152.24	147.40	198.000	2
47	6.7	2.99	2.82	4.56	200.33	188.94	305.520	2
48	5.2	3.17	3.19	4.99	164.84	165.88	259.480	2
49	7.3	3.72	3.07	4.63	271.56	224.11	337.990	2
50	5.4	3.71	3.16	4.68	200.34	170.64	252.720	2
51	4.6	4.15	3.44	4.77	190.90	158.24	219.420	2
52	4.8	3.76	3.24	4.74	180.48	155.52	227.520	2
53	4.1	2.81	2.98	4.08	115.21	122.18	167.280	2
54	7.1	3.20	3.10	4.37	227.20	220.10	310.270	2
55	5.1	4.03	3.05	4.89	205.53	155.55	249.390	2
56	5.0	4.08	3.37	4.99	204.00	168.50	249.500	2
57	5.6	3.48	3.13	4.71	194.88	175.28	263.760	2
58	4.3	3.76	3.41	4.49	161.68	146.63	193.070	2
59	6.6	3.09	2.83	4.56	203.94	186.78	300.960	2
60	5.0	3.60	3.27	5.07	180.00	163.50	253.500	2

Row	MY	F%	P%	L%	F	P	L	
61	7.3	3.95	3.04	4.60	288.35	221.92	335.800	2
62	4.7	3.48	3.22	4.72	163.56	151.34	221.840	2
63	5.0	4.41	3.40	4.76	220.50	170.00	238.000	2
64	4.8	3.69	3.17	4.81	177.12	152.16	230.880	2
65	3.8	3.46	2.92	4.07	131.48	110.96	154.660	2
66	6.7	4.21	2.94	4.80	282.07	196.98	321.600	2
67	4.1	3.90	2.97	4.94	159.90	121.77	202.540	2
68	4.5	4.51	3.28	5.14	202.95	147.60	231.300	2
69	5.3	3.82	3.32	4.78	202.46	175.96	253.340	2
70	3.8	3.62	3.87	4.51	137.56	147.06	171.380	2
71	7.2	2.96	2.85	4.45	213.12	205.20	320.400	2
72	5.1	3.90	3.24	5.12	198.90	165.24	261.120	2
73	7.7	3.45	3.05	4.60	265.65	234.85	354.200	2
74	4.6	3.42	3.32	4.67	157.32	152.72	214.820	2
75	5.3	3.70	3.36	4.80	196.10	178.08	254.400	2
76	4.9	3.62	3.25	4.89	177.38	159.25	239.610	2
77	3.6	3.20	2.91	4.04	115.20	104.76	145.440	2
78	7.1	4.20	2.90	4.78	298.20	205.90	339.380	2
79	4.3	3.94	3.10	4.93	169.42	133.30	211.990	2
80	4.3	4.54	3.41	5.16	195.22	146.63	221.880	2
81	6.5	3.24	3.42	4.84	210.60	222.30	314.600	2
82	4.1	3.29	3.78	4.54	134.89	154.98	186.140	2
83	6.5	2.91	2.86	4.55	189.15	185.90	295.750	2
84	5.1	3.47	3.20	5.09	176.97	163.20	259.590	2
85	7.4	3.51	3.02	4.65	259.74	223.48	344.100	2
86	4.4	3.34	3.29	4.72	146.96	144.76	207.680	2
87	4.4	3.87	3.34	4.81	170.28	146.96	211.640	2
88	4.7	3.71	3.24	4.88	174.37	152.28	229.360	2
89	3.1	2.83	2.93	4.14	87.73	90.83	128.340	2
90	6.3	3.58	2.90	4.79	225.54	182.70	301.770	2
91	4.0	4.16	3.06	4.98	166.40	122.40	199.200	2
92	4.4	4.10	3.38	5.08	180.40	148.72	223.520	2
93	6.1	3.66	3.42	4.82	223.26	208.62	294.020	2
94	3.9	3.15	3.79	4.50	122.85	147.81	175.500	2
95	6.5	3.26	2.82	4.51	211.90	183.30	293.150	2
96	4.5	3.28	3.19	5.12	147.60	143.55	230.400	2
97	7.4	3.36	3.05	4.80	248.64	225.70	355.200	2
98	4.7	3.57	3.40	4.77	167.79	159.80	224.190	2
99	6.0	4.16	3.36	4.85	249.60	201.60	291.000	2
100	4.5	3.99	3.24	4.87	179.55	145.80	219.150	2
101	3.4	3.21	2.99	4.04	109.14	101.66	137.360	2
102	6.1	3.78	2.93	4.84	230.58	178.73	295.240	2
103	3.9	4.60	3.13	4.98	179.40	122.07	194.220	2
104	4.0	4.02	3.87	5.10	160.80	154.80	204.000	2
105	5.7	4.34	3.51	4.91	247.38	200.07	279.870	2
106	3.4	3.58	4.06	4.47	121.72	138.04	151.980	2
107	6.5	3.31	2.81	4.65	215.15	182.65	302.250	2
108	4.8	3.98	3.21	5.24	191.04	154.08	251.520	2
109	7.4	3.73	3.02	4.88	276.02	223.48	361.120	2
110	3.9	3.84	3.43	4.84	149.76	133.77	188.760	2
111	5.4	3.95	3.46	4.93	213.30	186.84	266.220	2
112	4.0	3.55	3.22	4.89	142.00	128.80	195.600	2
113	2.4	3.14	3.03	4.06	75.36	72.72	97.440	2
114	6.5	5.51	2.88	4.80	358.15	187.20	312.000	2
115	3.9	4.18	3.16	4.98	163.02	123.24	194.220	2
116	3.9	3.87	3.95	5.06	150.93	154.05	197.340	2
117	5.6	4.10	3.50	4.89	229.60	196.00	273.840	2
118	3.0	3.70	4.20	4.42	111.00	126.00	132.600	2
119	6.3	3.58	2.79	4.64	225.54	175.77	292.320	2
120	4.7	3.77	3.27	5.19	177.19	153.69	243.930	2
121	7.7	3.69	3.18	4.73	284.13	244.86	364.210	2

Row	MY	F%	P%	L%	F	P	L	
122	4.2	3.39	3.35	4.84	142.38	140.70	203.280	2
123	6.0	3.96	3.41	4.91	237.60	204.60	294.600	2
124	4.6	3.99	3.20	4.86	183.54	147.20	223.560	2
125	2.8	3.00	3.12	3.74	84.00	87.36	104.720	2
126	6.2	3.41	3.01	4.86	211.42	186.62	301.320	2
127	3.7	3.88	3.29	4.85	143.56	121.73	179.450	2
128	4.1	3.43	4.19	5.05	140.63	171.79	207.050	2
129	5.7	4.11	3.65	4.85	234.27	208.05	276.450	2
130	3.7	3.00	4.14	4.57	111.00	153.18	169.090	2
131	6.5	3.07	2.87	4.54	199.55	186.55	295.100	2
132	5.0	3.57	3.32	5.22	178.50	166.00	261.000	2
133	7.5	3.75	3.18	4.65	281.25	238.50	348.750	2
134	4.5	3.62	3.36	4.73	162.90	151.20	212.850	2
135	5.2	3.78	3.40	4.86	196.56	176.80	252.720	2
136	3.6	3.01	2.46	4.65	108.36	88.56	167.400	2
137	3.1	3.22	3.75	4.64	99.82	116.25	143.840	2
138	5.9	3.17	3.09	4.82	187.03	182.31	284.380	2
139	3.1	4.15	3.35	4.84	128.65	103.85	150.040	2
140	3.7	3.38	4.19	5.04	125.06	155.03	186.480	2
141	5.5	4.00	3.66	4.83	220.00	201.30	265.650	2
142	3.7	3.05	3.58	4.13	112.85	132.46	152.810	2
143	6.5	3.21	2.82	4.53	208.65	183.30	294.450	2
144	4.8	3.51	3.36	5.21	168.48	161.28	250.080	2
145	7.7	3.75	3.15	4.67	288.75	242.55	359.590	2
146	3.6	3.73	3.41	5.09	134.28	122.76	183.240	2
147	6.1	3.95	3.43	4.85	240.95	209.23	295.850	2
148	4.9	4.13	3.35	4.80	202.37	164.15	235.200	2
149	3.0	2.87	3.24	3.70	86.10	97.20	111.000	2
150	5.5	3.54	3.18	4.83	194.70	174.90	265.650	2
151	3.4	3.96	3.45	4.84	134.64	117.30	164.560	2
152	3.5	3.36	4.33	5.00	117.60	151.55	175.000	2
153	5.3	4.38	3.89	4.89	232.14	206.17	259.170	2
154	3.3	3.42	4.21	4.48	112.86	138.93	147.840	2
155	6.6	3.24	2.92	4.61	213.84	192.72	304.260	2
156	4.9	3.50	3.37	5.16	171.50	165.13	252.840	2
157	7.9	3.54	3.14	4.75	279.66	248.06	375.250	2
158	4.2	3.69	3.44	4.82	154.98	144.48	202.440	2
159	5.2	3.86	3.43	5.00	200.72	178.36	260.000	2
160	4.6	3.61	3.31	4.93	166.06	152.26	226.780	2
161	2.9	3.04	3.15	3.92	88.16	91.35	113.680	2
162	5.8	3.63	3.14	4.89	210.54	182.12	283.620	2
163	3.4	4.03	3.41	4.81	137.02	115.94	163.540	2
164	3.5	3.07	4.38	5.03	107.45	153.30	176.050	2
165	5.4	3.69	3.97	4.81	199.26	214.38	259.740	2
166	3.5	3.46	4.22	4.57	121.10	147.70	159.950	2
167	6.4	3.17	2.88	4.62	202.88	184.32	295.680	2
168	4.7	3.86	3.33	5.21	181.42	156.51	244.870	2
169	8.1	3.67	3.19	4.83	297.27	258.39	391.230	2
170	4.2	3.72	3.57	4.83	156.24	149.94	202.860	2
171	5.2	3.76	3.54	5.08	195.52	184.08	264.160	2
172	4.4	3.43	3.43	4.91	150.92	150.92	216.040	2
173	2.6	3.10	3.14	3.78	80.60	81.64	98.280	2
174	4.7	2.45	3.21	4.88	115.15	150.87	229.360	2
175	3.3	3.84	3.42	4.76	126.72	112.86	157.080	2
176	3.0	3.12	4.55	4.90	93.60	136.50	147.000	2
177	5.3	3.63	3.94	4.95	192.39	208.82	262.350	2
178	3.5	3.44	4.16	4.64	120.40	145.60	162.400	2
179	6.6	2.79	3.05	4.61	184.14	201.30	304.260	2
180	5.0	3.44	3.55	5.18	172.00	177.50	259.000	2
181	7.6	3.89	3.11	4.82	295.64	236.36	366.320	3
182	3.1	3.49	3.58	4.89	108.19	110.98	151.590	3

Row	MY	F%	P%	L%	F	P	L	
183	4.7	3.70	3.45	4.85	173.90	162.15	227.950	3
184	4.6	3.66	3.42	4.73	168.36	157.32	217.580	3
185	2.8	3.13	3.18	3.42	87.64	89.04	95.760	3
186	5.8	4.62	3.18	4.70	267.96	184.44	272.600	3
187	3.0	4.33	3.46	4.34	129.90	103.80	130.200	3
188	3.0	3.21	4.45	4.51	96.30	133.50	135.300	3
189	4.9	4.49	4.03	4.92	220.01	197.47	241.080	3
190	3.0	3.84	4.22	4.46	115.20	126.60	133.800	3
191	5.9	3.09	3.00	4.51	182.31	177.00	266.090	3
192	4.7	4.06	3.65	4.48	190.82	171.55	210.560	3
193	6.9	3.90	3.00	4.70	269.10	207.00	324.300	3
194	2.6	4.60	3.17	4.74	119.60	82.42	123.240	3
195	4.4	4.64	3.37	4.77	204.16	148.28	209.880	3
196	3.7	4.10	3.53	4.61	151.70	130.61	170.570	3
197	2.4	3.27	3.16	3.36	78.48	75.84	80.640	3
198	5.4	4.97	3.10	4.61	268.38	167.40	248.940	3
199	2.5	4.55	3.20	4.43	113.75	80.00	110.750	3
200	2.7	3.98	4.45	4.37	107.46	120.15	117.990	3
201	4.4	4.58	3.96	4.87	201.52	174.24	214.280	3
202	3.0	4.32	4.04	4.51	129.60	121.20	135.300	3
203	5.3	3.85	2.84	4.45	204.05	150.52	235.850	3
204	4.5	4.50	3.51	4.65	202.50	157.95	209.250	3
205	6.7	4.09	2.99	4.67	274.03	200.33	312.890	3
206	3.0	3.69	3.17	4.77	110.70	95.10	143.100	3
207	4.0	5.54	3.24	4.55	221.60	129.60	182.000	3
208	3.4	3.94	3.64	4.29	133.96	123.76	145.860	3
209	2.0	3.85	3.15	2.91	77.00	63.00	58.200	3
210	5.1	5.12	3.04	4.66	261.12	155.04	237.660	3
211	2.3	4.83	3.15	4.49	111.09	72.45	103.270	3
212	2.4	3.82	4.26	4.21	91.68	102.24	101.040	3
213	3.9	5.84	3.88	4.67	227.76	151.32	182.130	3
214	2.5	5.56	4.03	4.38	139.00	100.75	109.500	3
215	4.6	4.81	2.94	4.24	221.26	135.24	195.040	3
216	3.9	4.56	3.48	4.58	177.84	135.72	178.620	3
217	7.1	3.77	3.04	4.71	267.67	215.84	334.410	3
218	3.2	3.72	3.28	4.72	119.04	104.96	151.040	3
219	5.2	5.17	3.23	4.66	268.84	167.96	242.320	3
220	4.1	4.64	3.30	4.56	190.24	135.30	186.960	3
221	2.3	3.92	3.12	3.41	90.16	71.76	78.430	3
222	5.5	5.26	2.96	4.68	289.30	162.80	257.400	3
223	2.3	4.88	3.07	4.65	112.24	70.61	106.950	3
224	2.9	3.26	4.26	4.72	94.54	123.54	136.880	3
225	4.1	5.43	3.75	4.88	222.63	153.75	200.080	3
226	2.9	4.57	3.98	4.52	132.53	115.42	131.080	3
227	5.6	3.59	2.85	4.53	201.04	159.60	253.680	3
228	4.7	3.73	3.32	4.99	175.31	156.04	234.530	3
229	7.3	3.63	3.06	4.61	264.99	223.38	336.530	3
230	3.0	3.65	3.41	4.60	109.50	102.30	138.000	3
231	3.4	4.66	3.46	4.71	158.44	117.64	160.140	3
232	3.5	4.31	3.60	4.51	150.85	126.00	157.850	3
233	2.2	3.37	3.24	3.03	74.14	71.28	66.660	3
234	5.0	4.39	2.98	4.73	219.50	149.00	236.500	3
235	3.0	4.44	3.20	4.35	133.20	96.00	130.500	3
236	2.3	3.58	4.65	4.18	82.34	106.95	96.140	3
237	3.8	4.94	3.98	4.66	187.72	151.24	177.080	3
238	2.5	4.28	4.41	4.21	107.00	110.25	105.250	3
239	5.1	3.54	2.92	4.25	180.54	148.92	216.750	3
240	4.6	3.91	3.40	4.67	179.86	156.40	214.820	3
241	6.6	4.30	3.08	4.57	283.80	203.28	301.620	3
242	3.1	4.17	3.57	4.38	129.27	110.67	135.780	3
243	3.2	6.26	3.53	4.44	200.32	112.96	142.080	3

Row	MY	F%	P%	L%	F	P	L	
244	3.3	4.56	3.72	4.32	150.48	122.76	142.560	3
245	2.0	3.91	3.17	2.99	78.20	63.40	59.800	3
246	3.9	4.89	3.09	4.59	190.71	120.51	179.010	3
247	1.8	5.22	3.30	4.23	93.96	59.40	76.140	3
248	1.6	4.49	4.74	3.84	71.84	75.84	61.440	3
249	3.2	5.84	3.91	4.47	186.88	125.12	143.040	3
250	1.5	6.27	4.81	4.03	94.05	72.15	60.450	3
251	3.6	4.14	3.06	4.25	149.04	110.16	153.000	3
252	3.6	4.22	3.60	4.69	151.92	129.60	168.840	3
253	6.5	4.22	3.11	4.64	274.30	202.15	301.600	3
254	2.4	3.63	3.47	4.60	87.12	83.28	110.400	3
255	2.8	6.62	3.47	4.49	185.36	97.16	125.720	3
256	3.4	4.60	3.55	4.30	156.40	120.70	146.200	3
257	1.9	3.93	3.18	2.97	74.67	60.42	56.430	3
258	3.4	4.66	3.11	4.66	158.44	105.74	158.440	3
259	1.4	4.55	3.18	4.20	63.70	44.52	58.800	3
260	1.7	4.59	4.59	3.89	78.03	78.03	66.130	3
261	3.2	5.47	3.78	4.68	175.04	120.96	149.760	3
262	1.3	6.17	4.52	4.13	80.21	58.76	53.690	3
263	3.4	5.09	3.20	4.05	173.06	108.80	137.700	3
264	3.6	4.41	3.49	4.73	158.76	125.64	170.280	3
265	6.8	3.81	3.10	4.72	259.08	210.80	320.960	3
266	2.7	3.65	3.38	4.64	98.55	91.26	125.280	3
267	4.0	5.18	3.24	4.71	207.20	129.60	188.400	3
268	3.7	3.87	3.40	4.78	143.19	125.80	176.860	3
269	1.9	3.86	3.17	3.29	73.34	60.23	62.510	3
270	4.8	4.58	3.01	4.70	219.84	144.48	225.600	3
271	1.3	4.22	3.11	4.25	54.86	40.43	55.250	3
272	1.8	3.41	4.44	4.29	61.38	79.92	77.220	3
273	4.0	4.19	3.66	4.80	167.60	146.40	192.000	3
274	2.0	4.44	4.17	4.48	88.80	83.40	89.600	3
275	4.4	3.58	2.98	4.58	157.52	131.12	201.520	3
276	4.7	3.73	3.42	5.07	175.31	160.74	238.290	3
277	6.6	3.80	3.13	4.66	250.80	206.58	307.560	3
278	2.9	3.87	3.48	4.55	112.23	100.92	131.950	3
279	3.9	4.85	3.42	4.74	189.15	133.38	184.860	3
280	3.5	4.11	3.47	4.69	143.85	121.45	164.150	3
281	1.8	3.10	3.32	3.03	55.80	59.76	54.540	3
282	4.6	4.29	3.07	4.69	197.34	141.22	215.740	3
283	1.4	5.59	3.25	4.07	78.26	45.50	56.980	3
284	1.6	3.32	4.53	3.79	53.12	72.48	60.640	3
285	3.4	5.05	3.91	4.67	171.70	132.94	158.780	3
286	1.4	5.09	4.56	4.15	71.26	63.84	58.100	3
287	4.3	4.13	2.97	4.26	177.59	127.71	183.180	3
288	3.9	4.16	3.51	4.71	162.24	136.89	183.690	3
289	5.9	4.22	2.98	4.26	248.98	175.82	251.340	3
290	2.1	3.98	3.48	4.18	83.58	73.08	87.780	3
291	3.7	5.65	3.47	4.32	209.05	128.39	159.840	3
292	3.2	4.63	3.59	4.09	148.16	114.88	130.880	3
293	1.7	2.96	3.38	2.49	50.32	57.46	42.330	3
294	4.1	4.68	3.21	4.42	191.88	131.61	181.220	3
295	1.7	5.38	3.43	3.96	91.46	58.31	67.320	3
296	1.2	3.61	5.26	2.75	43.32	63.12	33.000	3
297	3.3	5.15	3.95	4.53	169.95	130.35	149.490	3
298	1.2	6.06	4.96	3.68	72.72	59.52	44.160	3
299	3.6	4.34	2.98	3.95	156.24	107.28	142.200	3
300	3.7	4.85	3.52	4.44	179.45	130.24	164.280	3
301	6.1	4.32	3.04	4.35	263.52	185.44	265.350	3
302	2.3	4.62	3.46	4.04	106.26	79.58	92.920	3
303	2.9	5.71	3.49	4.43	165.59	101.21	128.470	3
304	2.6	4.75	3.38	4.27	123.50	87.88	111.020	3

Row	MY	F%	P%	L%	F	P	L	
305	1.1	2.94	3.14	2.26	32.34	34.54	24.860	3
306	4.0	4.66	3.10	4.41	186.40	124.00	176.400	3
307	1.4	4.70	3.31	3.88	65.80	46.34	54.320	3
308	0.8	3.57	5.13	2.78	28.56	41.04	22.240	3
309	3.3	5.46	4.44	4.09	180.18	146.52	134.970	3
310	0.8	5.57	4.85	3.81	44.56	38.80	30.480	3
311	3.2	4.74	3.01	3.89	151.68	96.32	124.480	3
312	3.5	4.60	3.45	4.51	161.00	120.75	157.850	3
313	7.0	4.06	3.17	4.46	284.20	221.90	312.200	3
314	2.2	3.83	3.41	4.20	84.26	75.02	92.400	3
315	4.1	5.06	3.37	4.45	207.46	138.17	182.450	3
316	3.4	3.99	3.36	4.31	135.66	114.24	146.540	3
317	1.6	3.37	3.21	2.72	53.92	51.36	43.520	3
318	4.5	3.97	3.07	4.56	178.65	138.15	205.200	3
319	1.4	4.50	3.25	4.06	63.00	45.50	56.840	3
320	1.0	2.64	4.97	3.07	26.40	49.70	30.700	3
321	3.5	5.23	3.72	4.51	183.05	130.20	157.850	3
322	1.4	4.71	4.72	3.83	65.94	66.08	53.620	3
323	4.2	3.67	2.88	4.28	154.14	120.96	179.760	3
324	4.2	4.02	3.47	4.78	168.84	145.74	200.760	3
325	7.0	4.05	3.20	4.51	283.50	224.00	315.700	4
326	2.3	4.00	3.52	4.21	92.00	80.96	96.830	4
327	3.3	4.92	3.50	4.67	162.36	115.50	154.110	4
328	3.2	4.02	3.36	4.28	128.64	107.52	136.960	4
329	1.3	1.96	3.37	2.63	25.48	43.81	34.190	4
330	4.2	4.62	3.14	4.51	194.04	131.88	189.420	4
331	1.3	4.38	3.37	3.64	56.94	43.81	47.320	4
332	0.9	2.35	5.12	3.07	21.15	46.08	27.630	4
333	3.3	4.98	3.94	4.47	164.34	130.02	147.510	4
334	0.9	4.13	5.03	3.80	37.17	45.27	34.200	4
335	3.7	3.59	2.96	4.12	132.83	109.52	152.440	4
336	4.0	3.93	3.55	4.76	157.20	142.00	190.400	4
337	7.0	3.52	2.96	4.67	246.40	207.20	326.900	4
338	2.4	3.63	3.28	4.23	87.12	78.72	101.520	4
339	4.7	4.30	3.35	4.51	202.10	157.45	211.970	4
340	3.3	3.83	3.17	4.47	126.39	104.61	147.510	4
341	1.3	2.74	3.16	2.95	35.62	41.08	38.350	4
342	4.2	3.22	2.93	4.68	135.24	123.06	196.560	4
343	1.3	3.67	3.42	3.86	47.71	44.46	50.180	4
344	1.2	1.69	5.88	3.00	20.28	70.56	36.000	4
345	3.4	4.54	3.85	4.65	154.36	130.90	158.100	4
346	1.0	4.27	5.25	3.78	42.70	52.50	37.800	4
347	4.3	3.26	2.72	4.31	140.18	116.96	185.330	4
348	4.4	3.49	3.38	4.84	153.56	148.72	212.960	4
349	7.7	3.31	2.75	4.39	254.87	211.75	338.030	4
350	2.0	3.96	3.40	4.22	79.20	68.00	84.400	4
351	4.3	3.78	3.37	4.75	162.54	144.91	204.250	4
352	3.3	3.71	3.14	4.47	122.43	103.62	147.510	4
353	1.3	2.88	2.90	3.86	37.44	37.70	50.180	4
354	4.8	3.74	2.94	4.65	179.52	141.12	223.200	4
355	1.2	3.79	3.50	3.78	45.48	42.00	45.360	4
356	0.6	1.55	5.48	2.56	9.30	32.88	15.360	4
357	3.3	4.41	3.85	4.55	145.53	127.05	150.150	4
358	0.9	4.51	5.58	3.47	40.59	50.22	31.230	4
359	4.0	3.36	3.12	4.61	134.40	124.80	184.400	4
360	4.2	2.63	4.92	4.24	110.46	206.64	178.080	4
361	7.0	3.41	2.95	4.75	238.70	206.50	332.500	4
362	1.9	4.06	3.51	4.18	77.14	66.69	79.420	4
363	2.8	3.67	3.37	4.85	102.76	94.36	135.800	4
364	3.0	3.56	3.20	4.33	106.80	96.00	129.900	4
365	1.3	2.24	2.91	2.91	29.12	37.83	37.830	4

Row	MY	F%	P%	L%	F	P	L	
366	4.9	4.04	2.89	4.95	197.96	141.61	242.550	4
367	1.2	4.05	3.57	3.82	48.60	42.84	45.840	4
368	0.6	2.30	5.95	3.15	13.80	35.70	18.900	4
369	3.4	4.22	3.78	4.66	143.48	128.52	158.440	4
370	0.9	3.91	5.53	3.55	35.19	49.77	31.950	4
371	4.1	3.08	2.76	4.35	126.28	113.16	178.350	4
372	4.2	3.79	3.38	4.81	159.18	141.96	202.020	4
373	7.4	3.42	2.89	4.67	253.08	213.86	345.580	4
374	1.8	3.89	3.53	4.15	70.02	63.54	74.700	4
375	3.9	3.68	3.36	4.68	143.52	131.04	182.520	4
376	2.8	3.88	3.30	4.46	108.64	92.40	124.880	4
377	1.0	3.00	2.93	3.84	30.00	29.30	38.400	4
378	4.6	3.59	2.93	4.65	165.14	134.78	213.900	4
379	1.1	3.61	3.68	3.90	39.71	40.48	42.900	4
380	0.4	2.15	4.25	2.88	8.60	17.00	11.520	4
381	3.2	4.32	3.96	4.63	138.24	126.72	148.160	4
382	0.7	3.70	4.37	4.22	25.90	30.59	29.540	4
383	3.7	3.32	4.35	3.87	122.84	160.95	143.190	4
384	4.0	2.95	4.66	3.93	118.00	186.40	157.200	4
385	7.2	3.61	2.80	4.60	259.92	201.60	331.200	4
386	1.7	4.45	3.45	3.88	75.65	58.65	65.960	4
387	4.0	4.42	3.36	4.70	176.80	134.40	188.000	4
388	2.6	4.14	3.32	4.21	107.64	86.32	109.460	4
389	1.3	2.90	2.79	2.68	37.70	36.27	34.840	4
390	4.3	3.98	2.96	4.62	171.14	127.28	198.660	4
391	0.8	4.20	3.79	3.70	33.60	30.32	29.600	4
392	0.2	2.23	6.09	3.02	4.46	12.18	6.040	4
393	3.2	4.63	3.96	4.49	148.16	126.72	143.680	4
394	0.4	3.62	5.13	3.80	14.48	20.52	15.200	4
395	3.8	3.13	2.77	4.26	118.94	105.26	161.880	4
396	3.7	3.79	3.37	4.94	140.23	124.69	182.780	4
397	7.4	3.66	2.88	4.65	270.84	213.12	344.100	4
398	1.5	4.35	3.64	3.98	65.25	54.60	59.700	4
399	3.7	4.23	3.44	4.73	156.51	127.28	175.010	4
400	2.6	3.98	3.38	4.31	103.48	87.88	112.060	4
401	1.1	2.88	2.82	2.86	31.68	31.02	31.460	4
402	4.4	4.04	2.93	4.61	177.76	128.92	202.840	4
403	0.8	3.79	3.83	3.68	30.32	30.64	29.440	4
404	0.2	2.76	5.82	3.18	5.52	11.64	6.360	4
405	2.7	4.61	4.17	4.51	124.47	112.59	121.770	4
406	0.4	3.52	5.44	3.43	14.08	21.76	13.720	4
407	3.3	3.14	2.86	4.33	103.62	94.38	142.890	4
408	3.6	4.12	3.35	4.87	148.32	120.60	175.320	4
409	6.9	3.85	2.98	4.75	265.65	205.62	327.750	4
410	1.2	3.86	3.72	3.68	46.32	44.64	44.160	4
411	4.8	4.46	3.36	4.39	214.08	161.28	210.720	4
412	2.0	5.24	3.50	4.24	104.80	70.00	84.800	4
413	1.0	2.51	3.32	3.03	25.10	33.20	30.300	4
414	4.3	4.20	2.99	4.52	180.60	128.57	194.360	4
415	0.6	3.99	4.09	3.75	23.94	24.54	22.500	4
416	0.2	2.22	6.26	2.56	4.44	12.52	5.120	4
417	2.0	5.34	4.93	3.96	106.80	98.60	79.200	4
418	0.3	5.06	5.85	3.42	15.18	17.55	10.260	4
419	3.0	3.80	2.84	4.19	114.00	85.20	125.700	4
420	3.4	4.09	3.32	4.85	139.06	112.88	164.900	4
421	7.3	3.52	2.92	4.59	256.96	213.16	335.070	4
422	1.1	3.99	3.72	3.50	43.89	40.92	38.500	4
423	2.7	4.12	3.32	4.69	111.24	89.64	126.630	4
424	2.0	4.03	3.51	4.26	80.60	70.20	85.200	4
425	0.8	2.01	3.13	3.05	16.08	25.04	24.400	4
426	4.3	3.01	3.06	4.56	129.43	131.58	196.080	4

Row	MY	F%	P%	L%	F	P	L	
427	0.6	3.64	4.00	3.79	21.84	24.00	22.740	4
428	0.2	1.94	5.42	2.66	3.88	10.84	5.320	4
429	3.4	4.65	4.20	4.40	158.10	142.80	149.600	4
430	0.3	3.87	5.78	3.25	11.61	17.34	9.750	4
431	3.2	3.03	2.79	4.30	96.96	89.28	137.600	4
432	3.6	3.78	3.34	4.82	136.08	120.24	173.520	4
433	7.0	3.56	3.02	4.71	249.20	211.40	329.700	4
434	1.2	3.73	4.33	3.39	44.76	51.96	40.680	4
435	3.3	4.41	3.47	4.71	145.53	114.51	155.430	4
436	1.6	4.68	3.93	3.91	74.88	62.88	62.560	4
437	1.1	2.41	3.07	2.68	26.51	33.77	29.480	4
438	2.8	3.53	3.19	4.58	98.84	89.32	128.240	4
439	0.5	3.47	4.34	3.56	17.35	21.70	17.800	4
440	0.2	2.76	5.75	3.36	5.52	11.50	6.720	4
441	2.5	4.39	4.54	4.51	109.75	113.50	112.750	4
442	0.2	3.91	4.79	3.73	7.82	9.58	7.460	4
443	3.2	3.48	2.93	4.29	111.36	93.76	137.280	4
444	3.5	3.97	3.49	4.94	138.95	122.15	172.900	4
445	7.4	3.76	3.02	4.70	278.24	223.48	347.800	4
446	0.8	3.95	4.66	3.30	31.60	37.28	26.400	4
447	3.8	4.78	3.46	4.57	181.64	131.48	173.660	4
448	1.6	4.90	4.12	4.26	78.40	65.92	68.160	4
449	1.0	2.94	3.30	2.90	29.40	33.00	29.000	4
450	4.4	4.72	3.17	4.52	207.68	139.48	198.880	4
451	0.4	4.39	4.65	3.46	17.56	18.60	13.840	4
452	0.2	2.39	5.85	2.87	4.78	11.70	5.740	4
453	2.0	5.05	4.66	4.30	101.00	93.20	86.000	4
454	0.3	3.57	6.79	3.28	10.71	20.37	9.840	4
455	2.9	3.19	2.96	4.31	92.51	85.84	124.990	4
456	3.7	4.41	3.46	4.85	163.17	128.02	179.450	4
457	7.5	3.44	3.07	4.67	258.00	230.25	350.250	4
458	0.4	3.76	4.89	3.14	15.04	19.56	12.560	4
459	3.1	4.58	3.46	4.58	141.98	107.26	141.980	4
460	1.7	4.91	4.16	4.02	83.47	70.72	68.340	4
461	0.9	2.68	3.65	3.47	24.12	32.85	31.230	4
462	3.8	4.97	3.19	4.47	188.86	121.22	169.860	4
463	0.3	3.75	4.30	3.22	11.25	12.90	9.660	4
464	0.1	2.30	5.28	2.89	2.30	5.28	2.890	4
465	1.5	5.13	4.81	4.24	76.95	72.15	63.600	4
466	0.1	4.45	6.29	3.64	4.45	6.29	3.640	4
467	2.8	3.71	3.31	4.56	103.88	92.68	127.680	4
468	3.3	3.55	3.34	3.77	117.15	110.22	124.410	4